COMMUNICATING SITUATION AWARENESS IN VIRTUAL ENVIRONMENTS

• Final Report •

HUMAN INTERFACE TECHNOLOGY LABORATORY
Washington Technology Center
University of Washington, Box 352142
Seattle, WA 98195-2142
206.543.5075 tel
206.543.5380 fax
http://www.hitl.washington.edu

REPORT DOCUMENTATION PA[illegible]	AFRL-SR-BL-TR-98- 0395	[illegible]d [illegible]-0188

1. AGENCY USE ONLY *(Leave blank)*	2. REPORT DATE April 1998	3. REPORT TYPE AND DATES COVERED Final Report 5.15.93 - 9.31.97

4. TITLE AND SUBTITLE

Communicating Situation Awareness in Virtual Environments

5. FUNDING NUMBERS

Grant #: F49620-93-1-0339

3484/HS

61103D

6. AUTHOR(S)

Maxwell J. Wells

7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES)

Human Interface Technology Laboratory
University of Washington
215 Fluke Hall Box 352142
Seattle, WA 98195

8. PERFORMING ORGANIZATION REPORT NUMBER

AFOSR 98-1

9. SPONSORING/MONITORING AGENCY NAME(S) AND ADDRESS(ES)

AFOSR/NL
URI FY93, Building 410
Bolling AFB, DC 20332-6448

10. SPONSORING/MONITORING AGENCY REPORT NUMBER

11. SUPPLEMENTARY NOTES

12a. DISTRIBUTION / AVAILABILITY STATEMENT

UNLIMITED

12b. DISTRIBUTION CODE

13. ABSTRACT *(Maximum 200 words)*

This report documents the work conducted by the HIT Lab during a four-year project titled "Communicating Situation Awareness in Virtual Environments." The project was funded under the MURI (Multi-disciplinary University Research Initiative), and was intended as "spin-up" funding to allow the Lab to achieve critical mass and momentum. As such, the goals of both the fund providers and fund recipients were successfully achieved. Over the course of the project over 30 experiments were conducted resulting in 76 publications. Support was provided for approximately 20 students, resulting in 9 theses and dissertations. A multi-disciplinary workshop was conducted, and there were active collaborations between researchers in this lab, with other labs, with government agencies and with commercial companies. The benefits of this collaboration are beginning to take effect. The focus of the research effort was tightened during the last year of the project to address five key areas. The results from experiments investigating four of these five areas are presented in this report, along with a cumulative list of all of the publications.

14. SUBJECT TERMS	15. NUMBER OF PAGES
situation awareness, virtual environments, presence, metrics	42
	16. PRICE CODE

17. SECURITY CLASSIFICATION OF REPORT	18. SECURITY CLASSIFICATION OF THIS PAGE	19. SECURITY CLASSIFICATION OF ABSTRACT	20. LIMITATION OF ABSTRACT
UNLIMITED			UNLIMITED

NSN 7540-01-280-5500

Standard Form 298 (Rev. 2-89)
Prescribed by ANSI Std. Z39-18
298-102

Communicating Situation Awareness

in

Virtual Environments

Final Report
for the period 15 May 93 - 31 September 1997

Submitted to the AFOSR

by

Human Interface Technology Laboratory
Washington Technology Center
Fluke Hall, P.O. Box 352142
University of Washington
Seattle, WA 98195

ABSTRACT

This report documents the work conducted by the HIT Lab during a four-year project titled "Communicating Situation Awareness in Virtual Environments." The project was funded under the MURI (Multi-disciplinary University Research Initiative), and was intended as "spin-up" funding to allow the Lab to achieve critical mass and momentum. As such, the goals of both the fund providers and fund recipients were successfully achieved. Over the course of the project over 30 experiments were conducted resulting in 76 publications. Support was provided for approximately 20 students, resulting in 9 theses and dissertations. A multi-disciplinary workshop was conducted, and there were active collaborations between researchers in this lab, with other labs, with government agencies and with commercial companies. The benefits of this collaboration are beginning to take effect.

The focus of the research effort was tightened during the last year of the project to address five key areas: 1) Motion sickness in users of virtual environments 2) Collaborative multi-crew virtual environments 3) Situation awareness in spatialized auditory and spatialized visual environments 4) Human factors assessment of virtual interface tools 5) Human factors assessment of the virtual motion controller. The results from experiments investigating four of these five areas are presented in this report, along with a cumulative list of all of the publications.

CONTENTS

1. Research Objectives

The original research objectives of the project are outlined in previous interim reports. A set of new research objectives were worked out between February and May 1996, under the auspices of the AFOSR contract manager, Dr. John Tangney, and the new Principal Investigator[1], Dr. Max Wells. The general rubric of the program - the communication of situation awareness in virtual environments - remained the same. However the focus was sharpened to address the questions:

- Why should the Air Force invest in VR, i.e. what are the benefits?
- What enabling technologies and know-how are required to realize these benefits?

It was decided to concentrate on the five areas listed below. This report documents work conducted during the fourth and final year of the project, in four of these five areas. Work in one of the areas, spatialized auditory and visual environments, was discontinued during the final year of the project due to the sudden departure of one of the co-PIs.

1.1. Motion Sickness in Users of Virtual Environments

The objectives of this effort are: to improve the theory of causation of motion sickness (MS) in VR, to improve the measures of MS, to determine system factors that increase incidence of MS and to study methods of configuring systems and training users to minimize MS.

1.2. The Virtual Pilot (Collaborative, multi-crew virtual environments)

The objective of this research effort is to create a testbed in which to implement and test the concept and utility of geographically dispersed teams working together on collaborative tasks using computer-mediated communication technology, including virtual reality. This project has generated industry interest under the SHARE (Shared Augmented Reality) consortium of Boeing, GEC, Microvision, and the HIT Lab.

1.3. Situation Awareness in Spatialized Auditory and Spatialized Visual Virtual Environments

The objective of this research is to determine how information from augmented reality visual and auditory displays can be effectively integrated with existing cockpit information to enhance situational awareness. Research in this area was discontinued under AFOSR support with the departure of Dr. Woodrow Barfield.

1.4. Human Factors Assessment of Virtual Interface Tools

Among the major human factors issues surrounding the military use of virtual environments is the question of how to design the user interface so as to minimize its cognitive load while maximizing environment effectiveness. This activity evaluated the usability and utility of a series of immersive interface tools, widgets, and metaphors. The research goal is to determine the relative merits of each technique for a given task and domain.

1.5. Human Factors Assessment of the Virtual Motion Controller

The HIT Lab has developed a device - the Virtual Motion Controller (VMC) - for locomoting through virtual environments. The VMC allows hands-free operation, and uses intuitive foot and body action for moving through virtual environments. Our research objective is to compare the VMC with some other methods of moving through VR and quantify the benefits of using this new interface device.

---

[1] Dr Wells took over as Prinicipal Investigator for the final year of the project, effective June 1996.

2. Status Of The Research Effort

2.1. Motion Sickness in Users of Virtual Environments

2.1.1. Eye Movement Research

Current virtual interfaces imperfectly simulate the motion dynamics of the real world. These imperfections have a range of consequences which were explored in a Ph.D. thesis by Captain Mark Draper.

Conflicting visual and vestibular cues of self-motion are believed to drive physiological adaptations and simulator sickness, which raises significant health and safety issues surrounding virtual environment exposure. Research investigated the nature of human physiological adaptation to virtual interfaces through a detailed study of the vestibulo-ocular reflex (VOR). The VOR is a compensatory eye movement response that functions to keep the visual scene stabilized on the retina during head movements. The VOR is investigated because of its propensity to adapt to visual-vestibular sensory rearrangements and because symptomology during VOR adaptation is often quite similar to that of simulator sickness.

The main hypothesis under investigation holds that certain artifacts of virtual interfaces drive VOR gain and phase adaptation processes. Artifacts investigated included system time delays (between head movement initiation and visual scene response; 48 ms, 125 ms, and 250 ms) and virtual image scale-factor changes (e.g., scene magnification level: 0.5X, 1.0X, 2.0X). Measures of VOR adaptation included gain and phase response changes from baseline levels, while simulator sickness metrics included oral self reports and a post-exposure questionnaire (SSQ).

Results demonstrated that significant VOR gain adaptation magnitude and direction resulted from image scale factors that differed from 1.0X magnification (Figure 1). Simulator sickness reports were also affected by image scale factor (Figure 2). Time delays resulted in statistically significant VOR gain decreases and increases in phase lag, though simulator sickness did not increase with increasing time delays.

Information obtained from these studies were used to develop preliminary design guidelines for the reduction of unwanted interface-generated effects on the user (Draper, 1998).

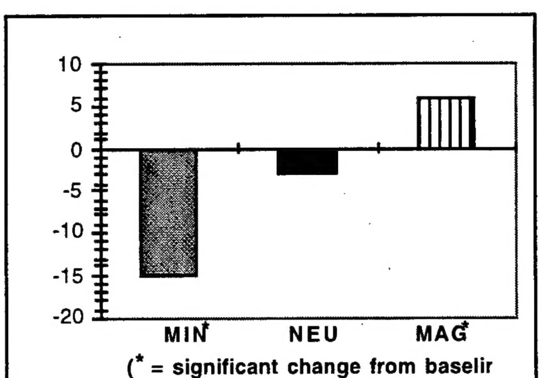


Figure 1: VOR Gain Adaptation by Image Scale Condition (0.5X minification, 1.0X neutral, 2.0X magnification)

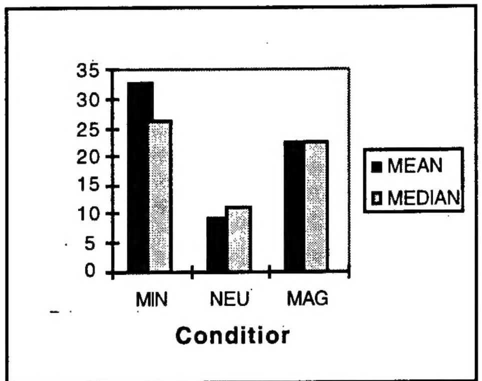


Figure 2: Simulator Sickness by Image Scale Condition

2.1.2. The Rest Frame Hypothesis

The following abstract describes the work in a Ph.D. thesis by Jerry Prothero:

Two fundamental human factors problems limit the application of virtual interfaces. The first is the lack of robust goodness measures to guide design; the second is simulator sickness. The rest frame hypothesis (RFH) is introduced to address these problems. The RFH, based on the observation that we have a strong perception that certain things are stationary, suggests that selected rest frames are fundamental to spatial perception. Presence, the sense of "being somewhere", is defined in terms of the choice of selected rest frame. "Objective" presence measures based on visual-inertial nulling are introduced in terms of this definition. Literature is reviewed suggesting that presence is one (but certainly not the only) measure for the quality of an interface. A technique motivated by the RFH is introduced for reducing simulator sickness, employing visual background manipulations. Other topics discussed include the application of foreground occlusions to head-mounted displays. (Prothero, 1998)

2.1.3. Intertial-Visual-Nulling

Introduction

The sense of presence (or of "being somewhere") is important to the study of virtual interfaces for two reasons. The first reason is that the feeling of being present in a computer-generated space is characteristic of virtual interfaces. Hence, any attempt to explain the psychology of virtual interfaces must explain presence. The second reason is that there is evidence that presence is related to the degree to which an interface is intuitive or conveys meaning. Conversely, a good presence measure may be one means to assess the quality of an interface.

Presence has typically been assessed with self-report measures, such as asking participants to rate their sense of presence on a scale of 1-7. Such measures are prone to several difficulties. The first is a lack of sensitivity: assigning numbers to fine gradations in mental state is not a task humans were designed for. The second is lack of consistency across individuals. Rating scales between different individuals are likely to be assigned in different ways. The third is that self-report measures for a given condition tend to depend on what it is compared to. Hence, it is difficult to compare data across experiments.

The research described here seeks to measure presence perceptually. The idea is that if presence reflects the degree to which someone is "pulled into" a visual scene, then presence should be measurable by setting up an experiment in which the visual cues conflict with cues from the external environment. The degree to which the visual cues overwhelm the external cues may define a scale for presence.

The "cross-over" measure introduced here sets up a conflict between inertial and visual self-motion cues in the horizontal plane. The effectiveness of two visual conditions was assessed in terms of their relative ability to overwhelm conflicting inertial motion cues. The measure consisted of finding the inertial amplitude below which participants "crossed-over" to perceiving the motion implied by the visual scene, even though they were trying to follow the inertial motion. Inertial and visual motion were restricted to the horizontal plane to avoid strong inertial cues from gravity.

The following questions about this inertial-visual nulling technique were addressed.

- Can it detect a predicted manipulation of presence? Specifically, can it find a difference between meaningful and random visual scenes?
- What is it's test-retest reliability?
- How is it related to self-report presence measures?
- How is it related to frame dependency measures?

"Frame dependency" is a standard psychological term referring to the degree to which different people are influenced by visual over conflicting inertial cues. It is hypothesized that between participants, a good presence measure should correlate with frame dependency.

Methods:

There were 12 adult participants. Participants were seated upright in a chair which could oscillate in the horizontal plane. They wore a Virtual Research VR4 HMD with a 48 deg FOV. Head-tracking was not used. The scene was displayed to both eyes, but was not stereoscopic. In order to keep the frame rate high (60 fps), the resolution was lowered to 240x320 pixels. Both the chair and the visual scene were oscillated at 0.1 Hz. The visual amplitude was fixed at 30 deg; the inertial amplitude was systematically varied as described below. The self-motion implied by the visual oscillation was set to trail the self-motion implied by the chair motion by 90 deg.

In each of two sessions, participants were exposed to two conditions: a picture of a scene from Maui (meaningful condition) or the same set of pixels randomized. At the beginning of each session, per exposure reported presence ratings were obtained for each condition following a one-minute period in which participants were asked to look around and gather their impressions of the scene.

Trials from each of the two conditions alternated on an ABBA pattern. Before each trial, the chair was started from rest and participants were asked to count down by 7's for 25 seconds from an arbitrary number, with their eyes closed. This served to distract them from "locking in" to the chair motion. They were then asked to count down by 7's for an additional 25 seconds with their eyes open. This gave the visual cues time to gain strength. Finally, they were asked to stop counting and to signal by switching a toggle the perceived

right/left extremes of the chair motion, while watching the visual scene. We recorded the mean phase angle of the participant's right/left responses from the intended inertial endpoint, and from the right/left endpoints implied by the visual stimulus.

At high inertial amplitudes, most participants had little difficulty correctly following the inertial motion while watching the visual scene. At lower amplitudes, most participants fell into "visual capture", signaling the visual endpoints of the motion even though the inertial endpoints were intended. The PEST procedure was used to systematically alter the inertial amplitude up and down between trials to find the inertial amplitude at which participants "crossed-over" between correctly signaling the inertial motion and falling into visual capture.

The two sessions were usually conducted on separate days, but always at least four hours apart. The sessions were identical except that the order of the first condition was counter-balanced across sessions and in one of the sessions an Embedded Figures Test (a measure of frame dependency) was administered.

Results:

For both the cross-over and reported presence data, a 3-factor ANOVA was computed with factors of participants (12),presence manipulation (meaningful/random) and session number (first/second). Three-way and higher interactions were collapsed into the error term.

For the cross-over measure, main effects were found for participants ($p < .01$) and treatment ($p < .01$). The treatment effect was in the direction of a higher inertial cross-over for the meaningful condition, as predicted. A participant-by-time interaction was also found ($p < .01$) indicating that some participants had a lower cross-over on the second session. No other effects were significant at $p < .05$.

For the reported presence measure, main effects were found for participants ($p < .01$) and treatment ($p < .05$). The treatment effect was in the direction of a higher inertial cross-over for the meaningful condition, as predicted. No other effects were significant at $p < .05$.

The test-retest correlations were good for both measures: 0.83 for the cross-over measure, and 0.80 for the reported presence measure.

The mean of the two sessions was taken for all participants on the two conditions. The correlations with the Embedded Figures Test are given below.

	Cross-over	Reported Presence
Meaningful	.45	.04
Random	.42	.28

Within subjects, the correlation between the magnitude of cross-over amplitudes and the magnitudes of reported presence was .06.

Within subjects, the correlation between the differences in the cross-over amplitude across the meaningful/random conditions, and the differences in reported presence across the meaningful/random conditions, was 0.38.

Discussion:

Both the cross-over and reported presence measures found a main effect for condition in the predicted direction (meaningful higher than random). Both measures showed reasonable test-retest reliability (0.83 and 0.80, respectively).

On limited data, the correlation of the cross-over measure with the embedded figures test scores appears to be higher than the correlation of the reported presence measure with the embedded figures test scores. However, this result has to be interpreted with caution for the small number of participants run.

It is not surprising that no relationship (0.06 correlation) was found between the magnitude of cross-over measures and the magnitude of reported presence. This is consistent with the lack of a standard scale, between participants, on how to assign numbers to mental states. However, there is a weak relationship (0.38 correlation) between differences in conditions across the two measures.

Conclusion:

This preliminary research has shown that the cross-over measure is capable of finding a main effect in the predicted direction which agrees with reported presence scores, and that the test-retest reliabilities for the two measures are similar. It finds a trend for a stronger relationship between the cross-over measure and frame dependency (as measured by the Embedded Figures Test) than between reported presence and frame dependency.

The advantage of the cross-over measure over reported presence is that the cross-over measure is based on the trade-off between visual and inertial motion perception, rather than on self-reported numbers. The cross-over measure is rooted more deeply in the function of the nervous system. While the current research has not shown this, it is plausible to suggest that a multi-modal nulling measure may have more meaning than reported presence between participants and between experiments.

Thus, between-subjects differences in the cross-over ratings may relate more strongly to performance differences than is true for reported presence, and cross-over amplitudes found in different experiments may be more easily comparable. These are both testable predictions.

2.2. The Virtual Pilot (ViP)

The problem

The problem that the ViP addresses is captured by the phrase "multi-crew performance in complex military systems." It is worth considering some of the changes to the mission that have precipitated the problem. These changes, and their implications, are outlined in Table 1.

Changes	**Implications**
Smaller military	No capacity for redundancy
Current or increasing tasking levels	Intelligent implementation of pieces
	Synergy between the pieces
Larger range	~~Good~~ great communications
	Dispersed teams
More uncertainty	Rapidly forming and mobilizing teams
	More flexibility
	More timely response
	Less time for training
UAVs, UCAVs	Manned missions become more critical and flexible
	Pilots need to deal with more information
	More reliance on timely information
	More reliance on advisors

Table 1. Changes in the mission, and the implications of those changes

Basically, there is an increased need for geographically dispersed teams to work together as cohesive units. These teams may be of the type currently implemented (intelligence analysis, fire control, air traffic control etc.), or they may be of a type which will form as a result of the changes that we are postulating.

An example of this new type of team is shown Figure 3. The drawing shows a shared virtual environment (VE) occupied by four people, three of whom are represented as avatars (computer-generated, human-controlled people). The drawing shows the scene from the real physical location (an AWACS) of the human in the center. He is wearing a see-through head-mounted display which allows him to see avatar representations of the other participants in virtual space, as well as his controls and displays in real space. The real location of the person on the extreme left is an Air Force Base, of the pilot is in an airborne F22, and of the person at the bottom of the drawing is in the Pentagon.

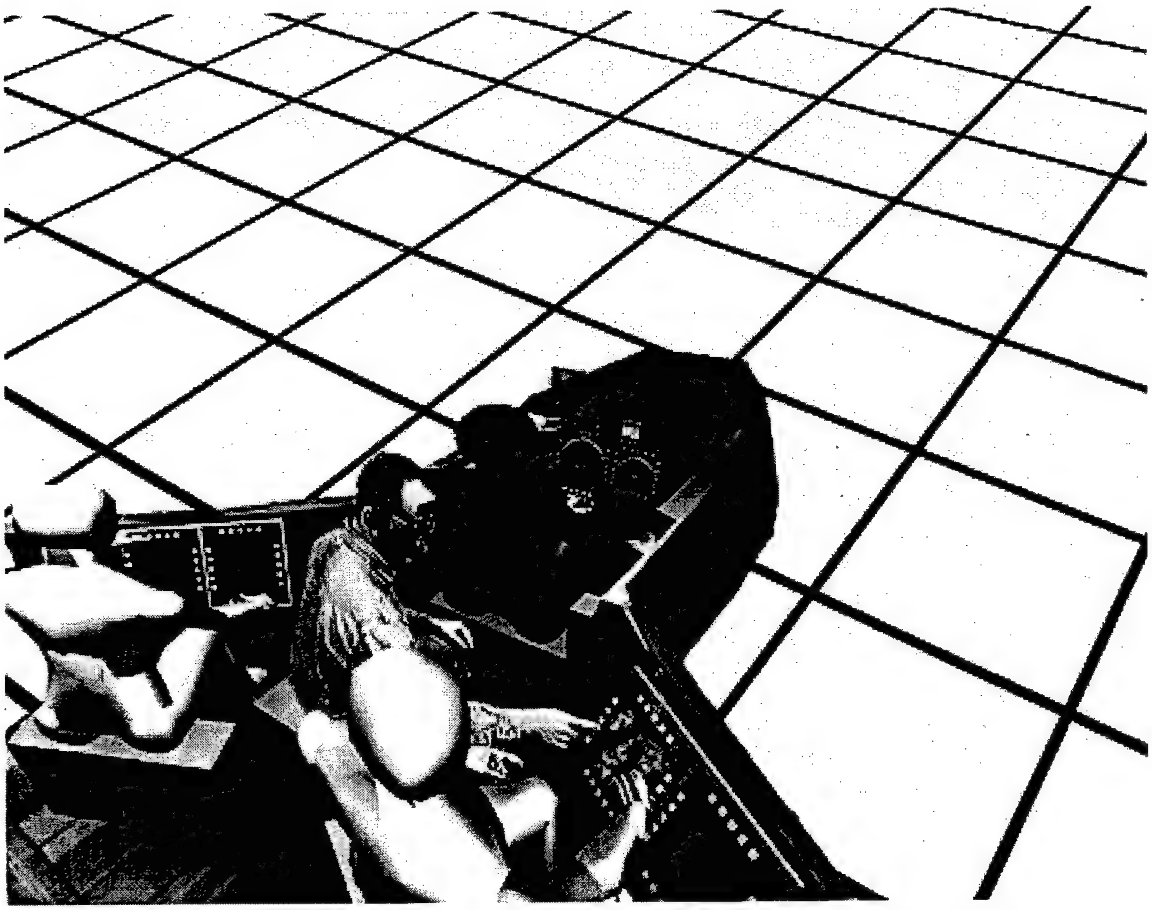


Figure 3. An example of geographically dispersed members of a team collaborating in the same virtual space.

The advent of UAVs and UCAVs will change the nature of manned missions. There will always be manned missions, because of the flexibility and performance that a real person can bring to the mission. It is for this very reason that those missions that are most sensitive, complex and dynamic will remain manned. Therefore, it is likely that the pilots performing those missions will be inundated with constantly changing information reflecting changing conditions. They will benefit from advisors - virtual backseaters - as depicted in the diagram.

There is another problem that currently exists. This is captured by the statement made by some fighter pilots that the key to air-to-air success is to turn of the AWACS radio. This could be because the perceived value of the AWACS advisors is low, or because the workload of the pilots is too high to deal with the additional information. We will argue that in the former case, the problem has more to do with limited communication channels and options between the pilot and the AWACS advisor rather than any lack of ability of the advisor. Also, that giving the advisor more information about the pilot's situation will increase the pilot's confidence in the advice being given. Furthermore, during periods of high workload the options being explored in the ViP concept will provide ways for the pilot to offload some of their task to the advisor.

The solution - the Virtual Pilot

Evolution of the ViP concept

The virtual pilot has undergone an evolution since its inception in September 1996. Since then there have been three ViPs. These are described below.

ViP (1), September 1996

In our first Virtual Pilot demonstration, two people sat back to back wearing non-see-through HMDs (see Figure 4). One played the role of pilot, the other the role of the co-pilot. Each could see a visual representation of the other when they looked to the side (see Figure 5). The virtual space around them contained moving targets. The co-pilot had to identify and track the targets so that the pilot could shoot them. The pilot also had to perform a tracking task. Both crew members had to collaborate in order to survive.

The lessons learned from this demonstration were:

1) Context. Some of the gestural communication that was exchanged between the participants alluded to context. The use of these contextual cues seemed to make communication easier.

2) Availability for communication. An important benefit of being able to see the other person, or at least an avatar representation, and what they were doing, was that it became possible to determine when the other person was available for communication.

3) Augmented reality. The demonstration provided information that would not have been visible in the real world. For example, where the co-pilot's hand and the pilot's head were pointing in space was visible to the other participant (each had a pointer attached to them). This disambiguated the contextual information and made communication easier.

4) Display design. Forcing the pilot to look at the co-pilot was not the most efficient way of designing an alerting display. It would have been better to have a head-mounted designator symbol showing the pilot where to look.

With these lessons in mind we designed the second ViP demonstration.

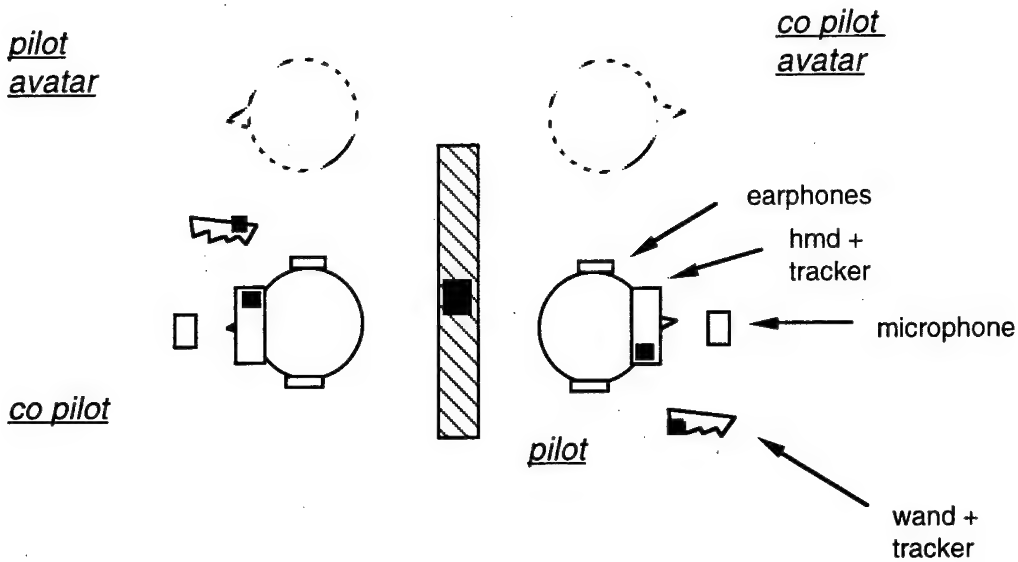


Figure 4. Plan view of the layout used in ViP 1.

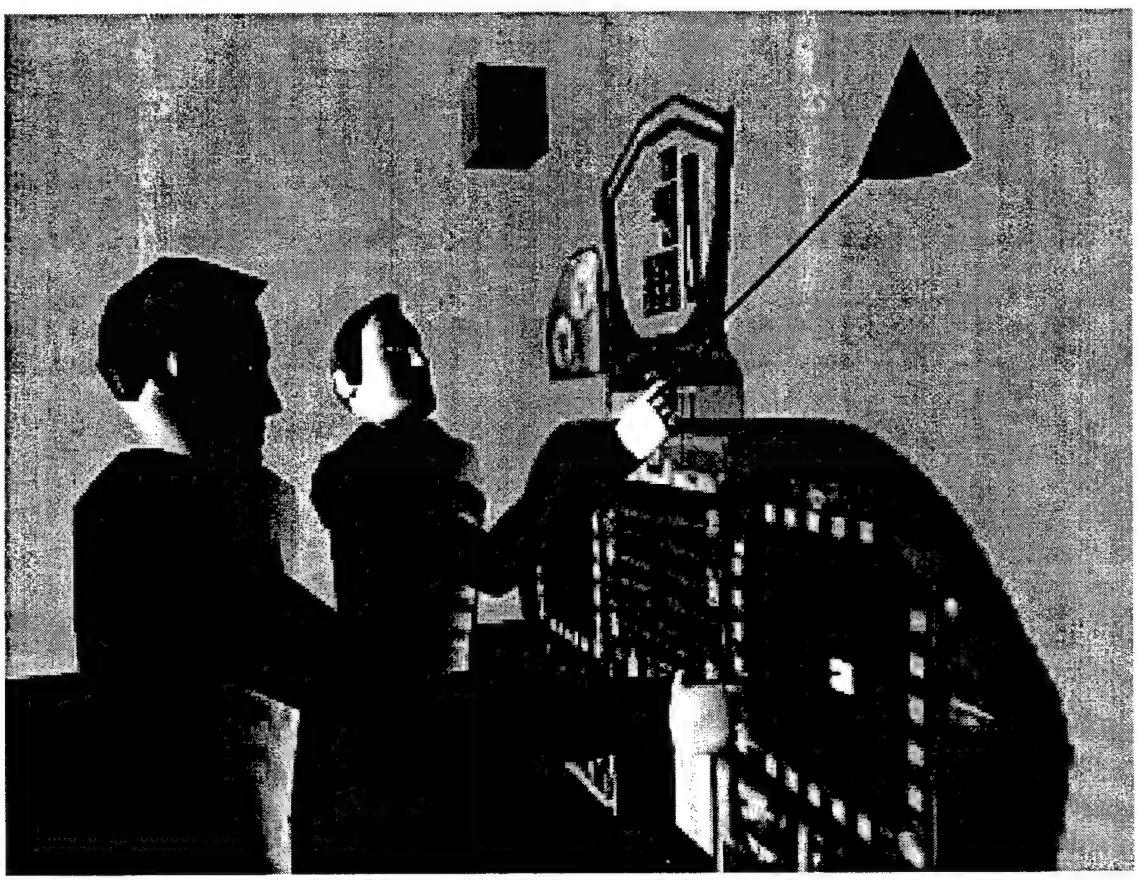


Figure 5. View of the pilot (right seat) and co-pilot (left seat) in the ViP 1 demonstration.

ViP (2), May 1997

In the second of our virtual pilot demonstrations we changed the emphasis from the pilot viewing the advisor to the advisor viewing the pilot. The pilot's task was to land on an aircraft carrier. The advisor viewed the pilot's avatar. By giving the advisor a view of the pilot's instruments, and their head position, we intended for the advisor to get a better understanding of what the pilot was thinking (a view inside their mind). This line of thinking resulted in the concept of "telesavance".

Telesavance is the communication of the state of someone's situation awareness. "Savance" comes from the term "savant" - a wise or knowledgeable person. Information about the pilot's SA is important. It allows the advisor to know what the pilot knows and doesn't know. In face-to-face encounters telesavance is communicated by the methods listed in Table 2. This certainly includes auditory and visual channels, and may include others. Some of the information may be used consciously and some may be used unconsciously (e.g. pupil dilation). Another important element of telesavance is the mental model that the advisor has which allows him to predict how the pilot may react. The combination of the communication channels and options, and the mental model, allows the advisor to be a better advisor. In contrast to the channels and options available in face-to-face communication, the current methods of communicating telesavance in aircraft are also shown in Table 2.

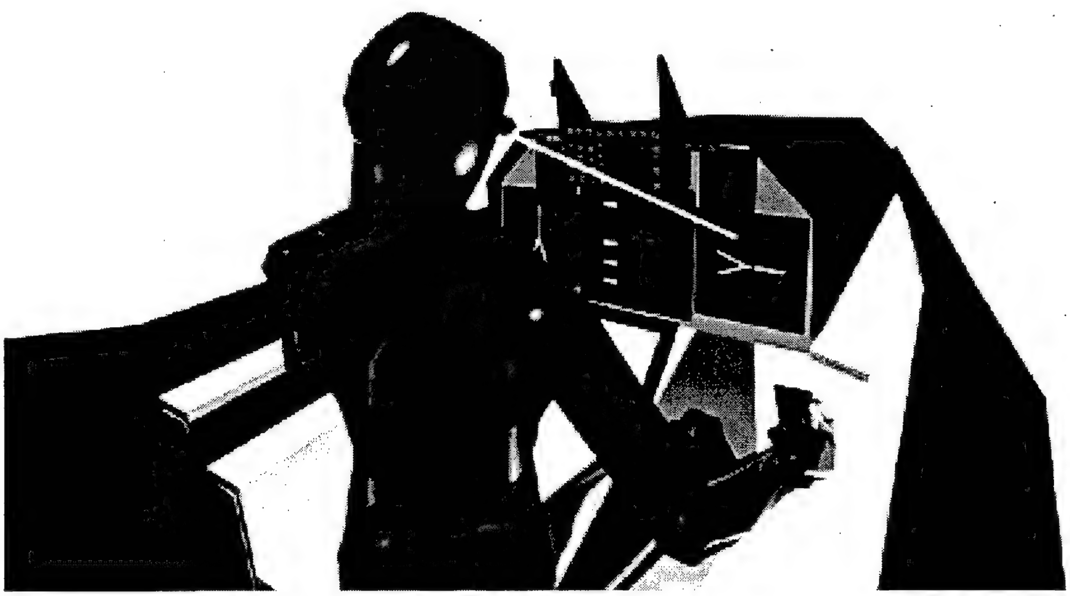


Figure 6. View of the pilot's avatar from the point of view of the advisor. The line extending from the pilot's head shows where his head is pointing. This was the arrangement in ViP 2.

Channels and options	Face-to-face	In aircraft
Verbal	√	√
Gestural	√	
Facial expression	√	
Shared information displays	√	
Responses to verbal	√	√
Responses to gesture	√	
Performance	√	√
Eye movement	√	
Pupil dilation	√	
Other physiological information	√	
blushing	√	
sweating	√	
breathing	√	√
trembling	√	
swallowing	√	√
tearing	√	
odor	√	

Table 2. How telesavance is communicated face-to-face and in aircraft.

ViP (3), October 1997

In our third ViP demonstration we measured the pilot's eye motion and allowed the advisor to view it via a see-through head-mounted display. The advisor saw a reticle with a decaying trail that corresponded to where the pilot was currently looking and had most recently looked. This was a demonstration of augmented reality. For this demonstration we used a commercially available flight simulator, and blanked out portions of the pilot's and advisor's screens to simulate the disparity in information between a pilot and an AWACS operator.

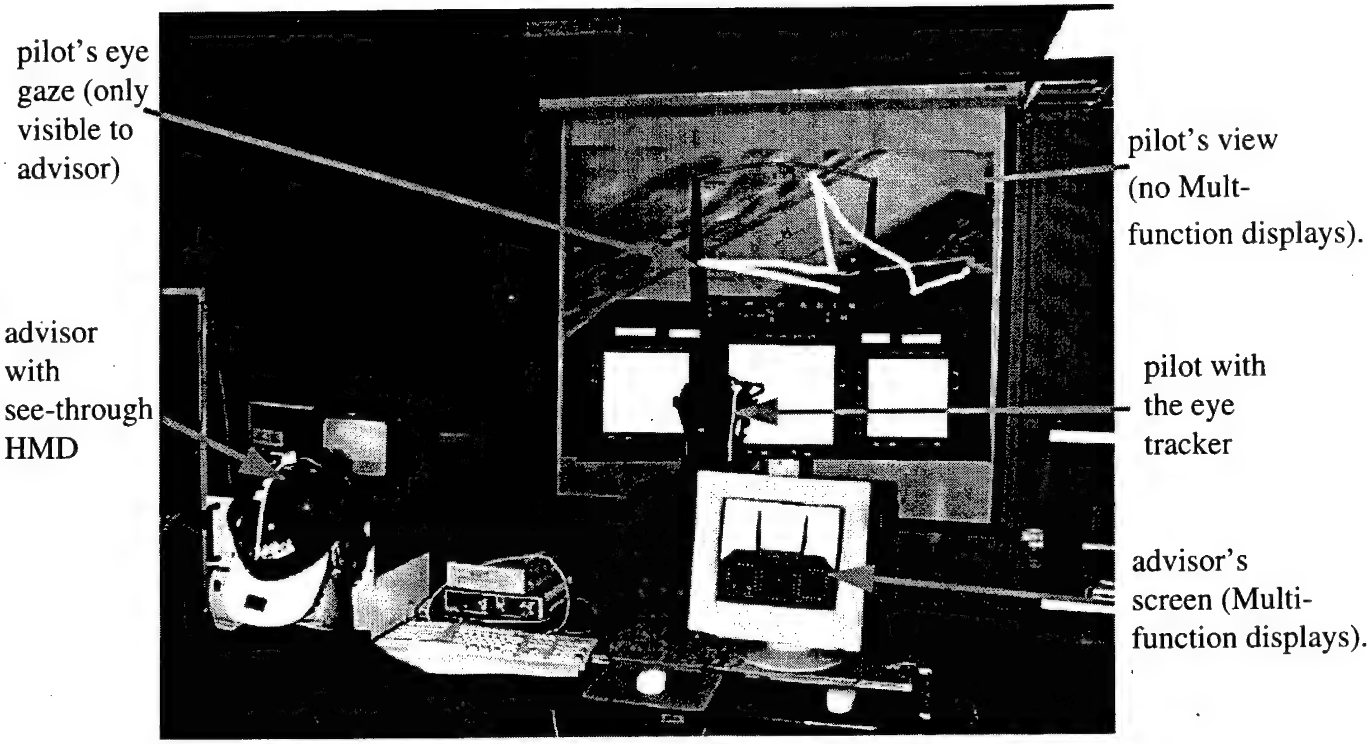


Figure 7. The pilot and advisor as arranged in ViP 3. The pilot saw a subset of the flight simulator information on the projection screen. The advisor saw a different subset on his monitor, but he could also see what the pilot saw by looking at the projection screen. Because the advisor wore a see-through HMD, he could also see the pilot's eye motion superimposed on the projection screen (augmented reality).

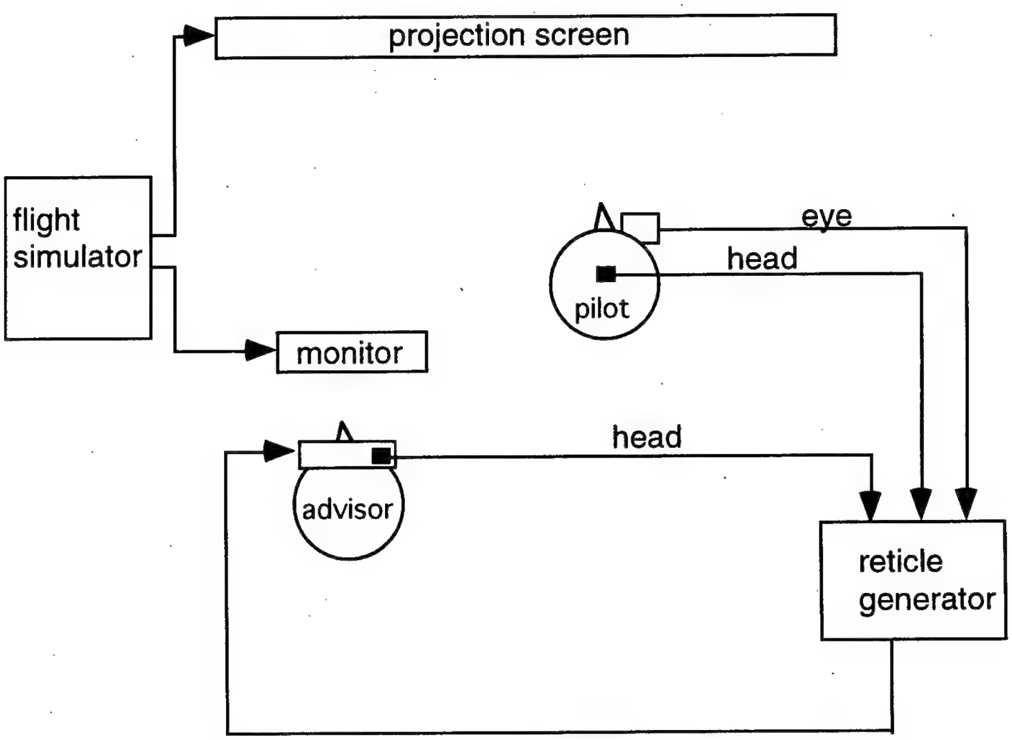


Figure 8. Component diagram from ViP 3. The combination of the pilot's eye and head motion (gaze) and the advisor's head motion were used to create a reticle that followed the pilot's gaze, and was visible through the advisor's HMD.

An experimental test of the concept

We have conducted an experiment to test the utility of the ViP concept. The experiment drew on elements refined from all of the ViP demonstrations. It was the first attempt at an empirical validation, and as such used a simple paradigm, a simple experimental design, and simple apparatus. We reasoned that we needed to determine whether or not there was an effect (i.e. an advantage of face-to-face communication over verbal-only communication) before we embarked on explorations of the nature and causes of that effect.

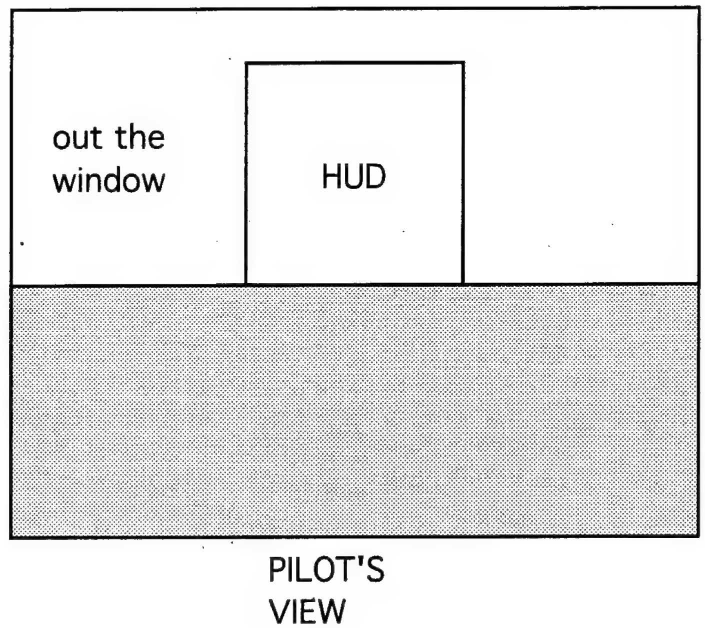
Our method of testing the hypothesis was to compare a low-tech method of communication, namely voice-only, with what we termed a high-tech communication method, and to measure mission performance, situation awareness of the pilot and advisor, and telesavance.

Apparatus

Our high-tech communication method was in fact a simple simulation of what could be achieved if we had equipment sophisticated enough to put two geographically dispersed members of a team in the same virtual space, with sufficient fidelity for them to think that they were sitting in the same physical space. We did this by actually putting them in the same physical space - thereby using physical proximity to simulate high-tech communication methods.

The experiment simulated a team of a fighter pilot and an AWACS operator. In order to do this we used a commercially available flight simulator (iF 22 from Interactive Magic). We used a video splitter to show the same scene on two CRT screens, and selectively blanked areas of both screens to simulate the disparity of information between a pilot and an AWACS operator. The information on each screen is shown in Figure 9. The pilot's view was essentially ego-centric, whereas the advisor's view was exo-centric. Figure 10 shows the arrangement of the two participants. In the high-tech condition the advisor could see both his own screen and the pilot's screen, and therefore increase his SA substantially. The pilot's view was the same in both conditions.

The choice of what flight simulator to use was made after an analysis of the available products. Over the past 10 years the advent of high performance PCs and graphics cards, and the market pull of the $16b computer games market have created flight simulators with a level of realism that matches the best military simulators. The game we decided on has a variety of missions, enemy skill levels and fighter performances. It is capable of being networked for head-to-head dogfights or group missions. The computer opponents and wingmen incorporate artificial intelligence, so that no two missions are exactly the same. The visual scenery is based on satellite imagery. Missions can be individually tailored and then saved and re-run . All this for $49.95.



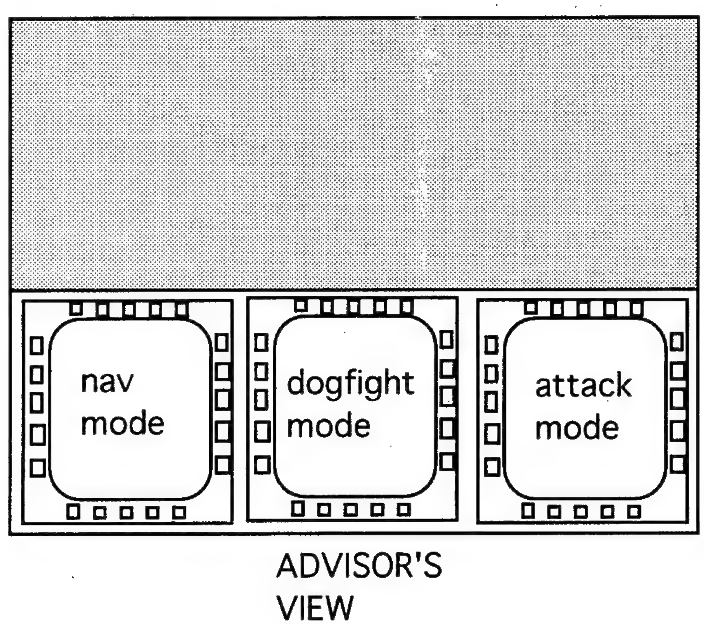


Figure 9. Information available on the pilot's and advisor's screens.

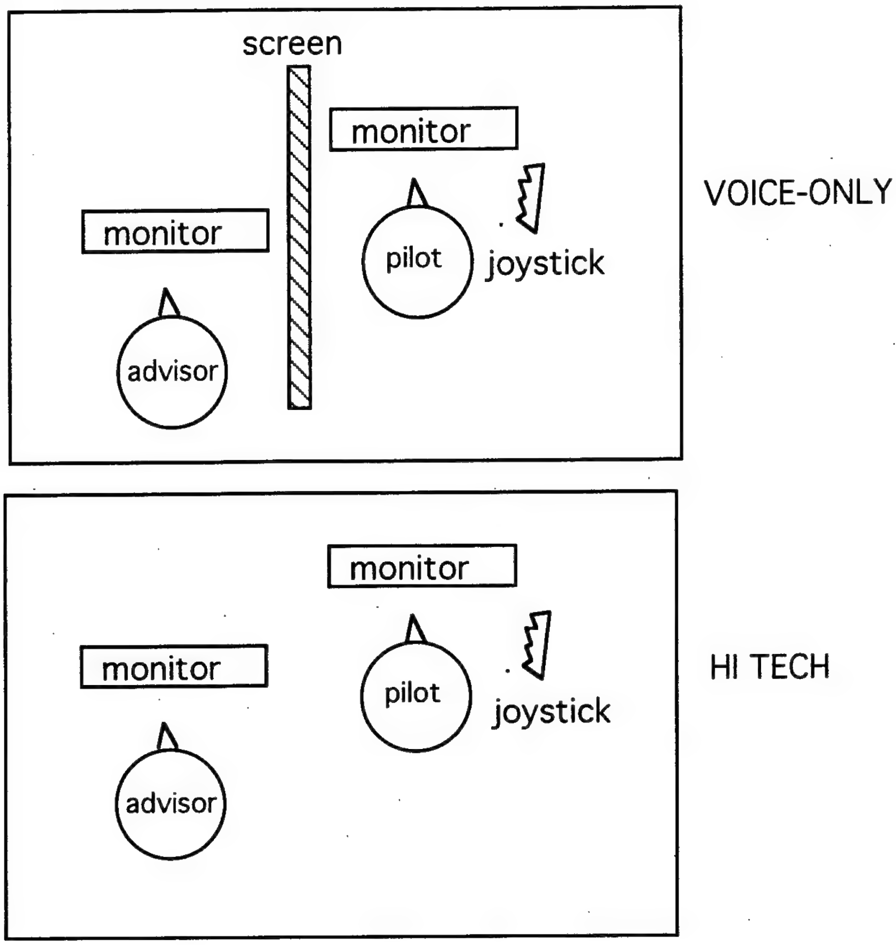


Figure 10. Arrangement of the pilot and advisor in the two experimental conditions.

Dependent variables
The dependent variables were chosen to measure performance, situation awareness (SA) and telesavance. For performance we used the simulators statistics that were calculated and made available at the end of each mission. These were Battle Damage Assessment (BDA, 0 - 100%), Result (poor, average, outstanding), effectiveness (0 - 100%), number of kills, mission duration, and number of crashes. SA was measured for both pilot and advisor using a modified Situation Awareness Global Assessment Technique (SAGAT) after Endsley (1995). It is unusual to measure SA for all members of a team. Very little research has focused on the team element in SA (Salas et al, 1995). Telesavance was measured indirectly using a series of visual analogue scales. Both the pilot and the advisor were asked to rate the amount of communication, the value of the communication, the instigator of communication, the advisor's performance and the pilot's performance. In addition, each trial was videotaped for later transaction analysis and objective measures of communication.

Experimental design
The subjects used in the data reported here were 11 civilian users of the game, and an ex Navy pilot instructor with over 2000 hours in fast jets, including carrier landings. The advisor was an expert civilian user.

The order of presentation of the two communication conditions was balanced across subjects. The sequence in which each subject was run was as follows;

Train to criterion - each subject was trained by the advisor and tested. Before being able to participate they had to be able to fly in an "Instant Action" scenario and achieve two air-to-air kills without being shot down. They had to do so once out of three trials.

Mission 1 - the subject embarked on their first mission, either in the hi-tech or voice-only condition. They were taken at 8 times normal speed to the edge of the battle area, which was a Combat Air Patrol over Bosnia. They were the squadron leader of a 4-man formation with 3 other F22s. At the designated waypoint the simulator was returned to normal speed and paused. A timer was started and the mission began. Three minutes later, and at subsequent 3 minute intervals during the mission the simulator was paused so that both the pilot and advisor could fill in the SAGAT questionnaire and the visual analogue scales. These were then graded before the mission was recommenced. The questionnaire was administered a maximum of four times in each mission, less if the person crashed.

Mission 2 - the subject embarked on the second mission, in the opposite condition to the first mission (i.e. voice-only after the high-tech condition, and vice versa). All other events were the same as in mission 1.

Results

Figure 10 shows mixed evidence of better performance in the hi tech condition. However the variability in the data mean that these differences were not significant. A closer examination of the data was conducted, by dividing the data into those from low experience pilots (n=5), and high experience pilots (n=6). Experience was assessed from a screening questionnaire. Figure 11 shows the results from the low experience pilots. There is evidence that their performance, as measured by most of the indicators, was worse in the hi tech condition. In contrast, Figure 12 shows the data from the more experienced pilots, in which there is evidence that performance improved in the hi tech condition. The data in Figure 13 provides some indication as to the cause of this difference. It would appear that in the hi tech condition the less experienced pilots were overwhelmed and their SA dropped. As a result, all of these pilots were shot down (Figure 11). The more experienced pilots, on the other hand, benefited from the increased information and their performance improved.

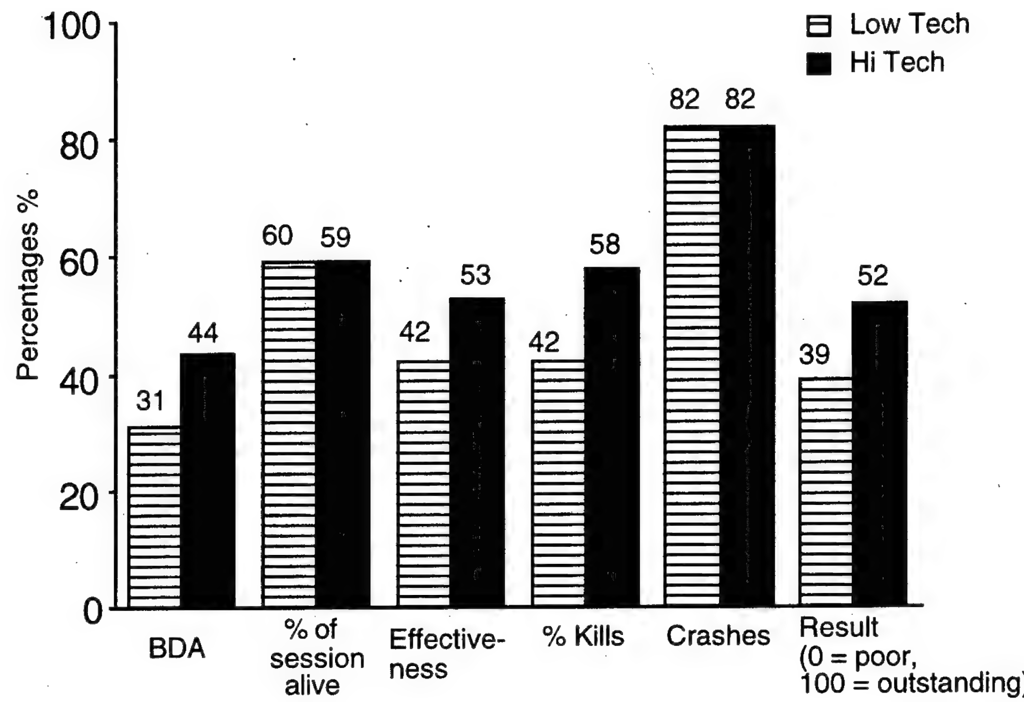


Figure 10. Mean performance data from 11 subjects

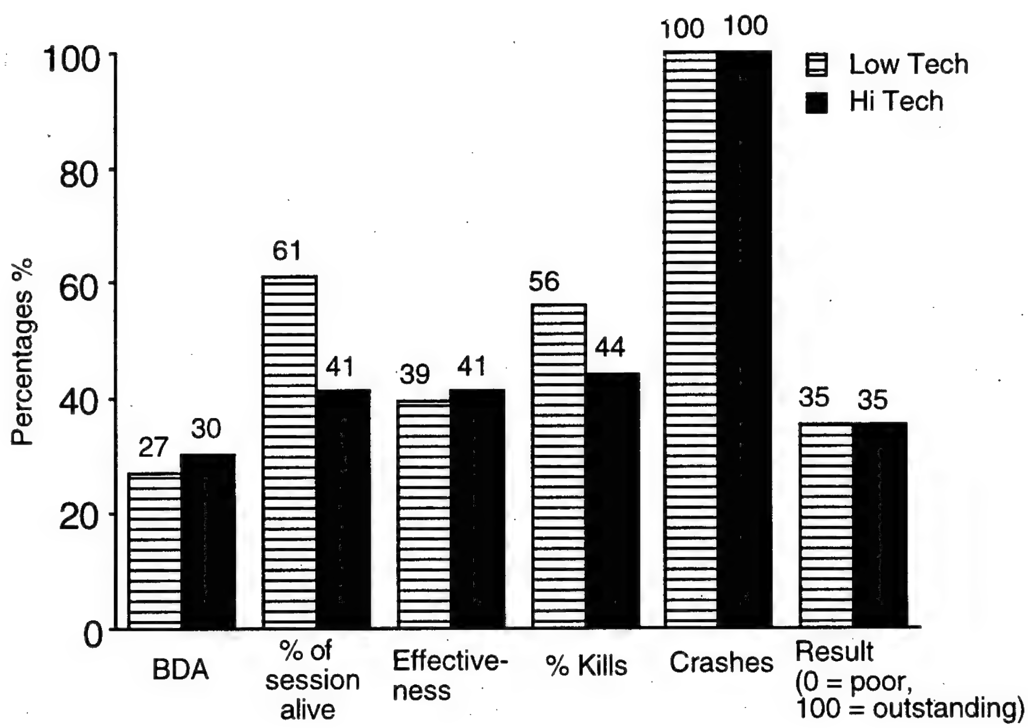


Figure 11. Performance data from the low experience pilots (n=5)

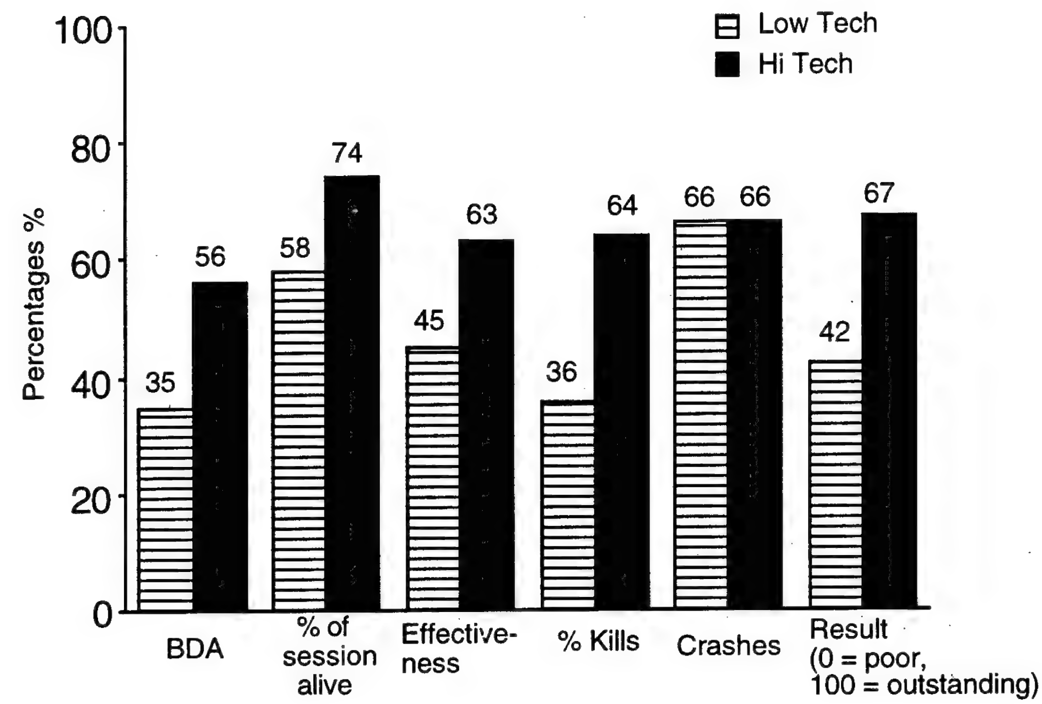


Figure 12. Performance data from the high experience pilots (n=6)

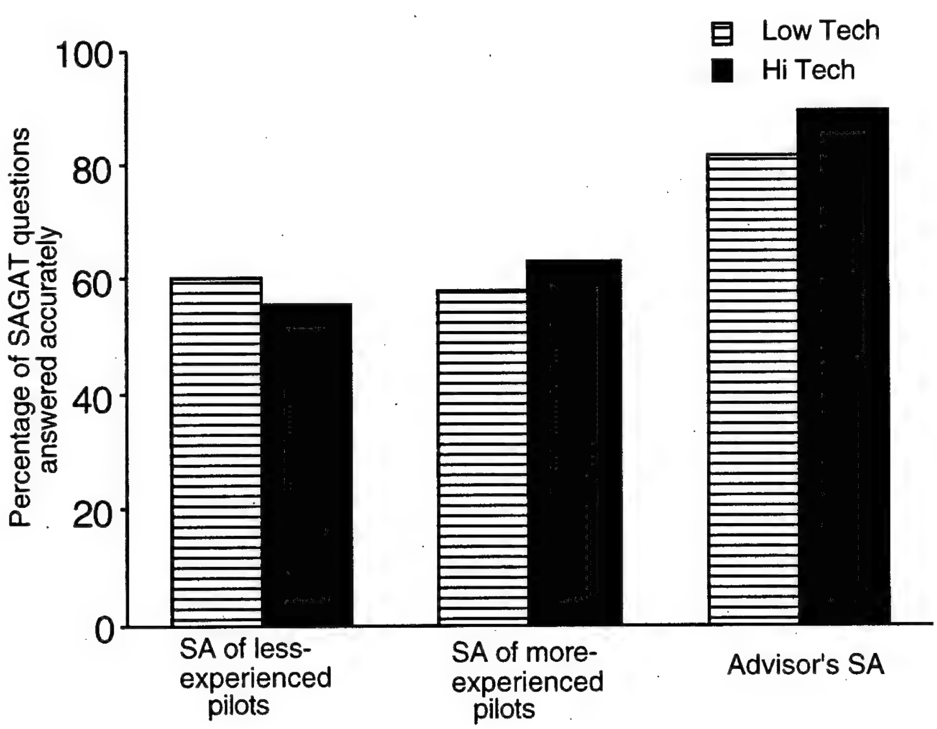


Figure 13. Situation awareness data from the low and high experience pilots, and the advisor.

Discussion of the results

The data suggest that the more experienced pilots were aided by the technology, resulting in higher SA and better performance. Less experienced pilots were overwhelmed by the added information and showed a performance decrement. This type of effect is consistent with the psychological literature. Experts process information more effectively than novices (by chunking etc.).

In the operational environment the people using the technology will be experts. Therefore, as a test of the utility of the techniques, the previous experiment needs to be extended to include experienced military pilots. This will be done in work currently supported by the Armstrong Laboratory, using pilots from Boeing. The HIT Lab has forged a relationship with Boeing in the performance of this work, described in Section 5.

Team composition

Sisinio Baldis
Rich Barker
William Elder
Hunter Hoffman
Stig Hollup
Kori Inkpen
Kegan Kandie
Kelly Reischel
Paul Schwartz
Daryl Smith
Andy Volk
Max Wells

References

Segal, L.D. (1994) Actions speak louder than words: how pilots use nonverbal information for crew communications. *Proceedings of the Human Factors and Ergonomics Society 38th Annual Meeting* pp. 21 - 25. Human Factors and Ergonomics Society, Santa Monica CA.

Endsley, Mica, R. (1995). Measurement of situation awareness in dynamic systems. *Human Factors*, 37, pp 65-84.

Salas, E., Prince, C., Baker, D.P., and Shrestha, L. (1995). Situation awareness in team performance: Implications for measurement and training. *Human Factors*, 37, 123-136.

2.3. Performance study of the Virtual Motion Controller

Abstract of a paper proposal to the Human Factors and Ergonomics Society by Peterson, Wells, Furness and Hunt.

Thirty subjects explored mazes in an immersive virtual environment. Half of the subjects used a joystick for maneuvering; the other half used a new type of body-controlled interface called the virtual motion controller (VMC). Maneuvering performance, as measured by the precision with which subjects followed a marked route, was slightly worse with the VMC than with the joystick. Route learning, as measured by the subjects' ability to replicate the route, was the same for both devices. Survey knowledge, or the ability to form a mental map of the space, and to use that to find alternative routes, was significantly better with the VMC than with the joystick. This enhancement in performance was conditional on maze difficulty. The more difficult the maze the greater was the performance benefits of using the VMC. The experiment provided evidence that the VMC can enhance certain components of navigation in virtual environments.

Introduction

When we navigate in the real world we have several types of sensory cues to tell us where we are and where we have been. These include cues from vision, the vestibular apparatus, the haptic and proprioceptive senses, and audition. Together these allow us to acquire knowledge about, and form a mental representation of, a space. Researchers have broken down this knowledge into route and survey knowledge (Thorndyke and Hayes-Roth, 1982). Route knowledge, also known as procedural knowledge, consists of the procedures required to find a set of targets in the world. Survey knowledge, also known as configurational knowledge consists of a more flexible "big picture" of the space that can be used, for example, to find alternative routes.

There is evidence that the human sensory apparatus is tuned to integrate information from several sensory modalities to create a single coherent sensation (Welch and Warren, 1986). When environmental information is limited to only one or two sensory modalities, interpretations of that environment can be misleading or inaccurate, thereby increasing the complexity of otherwise simple tasks (Sherrick and Cholewiak, 1986). Therefore, when computer-mediated interactions strip away information they do not provide the complete and expected information (even if this information may be "redundant") and may handicap performance (Durlach and Mavor, 1995).

Several researchers have attempted to explore navigation in virtual environments (e.g. Bliss et al, 1997, Regian et al, 1992, Ruddle et al, 1996, Satalich, 1995, Tlauka and Wilson, 1994, Witmer et al, 1996). Indeed, navigational training may be one of the "killer apps" of immersive VR. However, in most, if not all cases to date, the interfaces used stripped away many of the sensory stimuli and the research was conducted with relatively sparse sensory interaction.

In an attempt to put back some of the multi-sensory information, we created a new interface device, called the virtual motion controller or VMC (Wells, Peterson and Aten, 1996). The VMC uses the body to generate motion commands and provides some vestibular, haptic and proprioceptive cues. The research in this paper describes an experiment to compare the VMC with a more commonly used interface, in which mainly visual cues are provided. Our rationale was to first determine whether there was a difference, and if there was, to conduct further research to find out why. This is the first step in that experimental program.

Methods

Apparatus

A diagram of the apparatus for both controller conditions is shown in Figure 14. The head mounted display (HMD) was a Vi/O I Glasses ™ with a fully overlapped field of view of 32 degrees horizontal by 24 degrees vertical. The display in each eye consisted of an LCD with 320 pixels by 200 pixels. Subjects could see around the edges of the HMD, but an opaque visor blocked their view through the display area. Two computers controlled and generated the virtual world. Monocular images for display on the HMD were generated by a Silicon Graphics Onyx. The Onyx maintained a frame rate in excess of 20 frames per second. The input devices were a Polhemus Fast Track for measuring head motion, the virtual motion controller (VMC), or a joystick. The VMC consisted of a disc on which the subject stood (see Figure 15). It worked as a first order controller, turning displacements on the disc into velocities in the VE. Movements away from the center of the VMC resulted in motion in the virtual environment (VE) in the same direction as the movement on the VMC, and with a velocity proportional to the distance from the center. The joystick was a Sidewinder Pro, made by Microsoft. Forward/backward and left/right motion of the joystick caused forward/backward translational and left/right rotational velocity in the VE, proportional to the amount of joystick movement. In both conditions, yaw axis rotational displacement of the head caused yaw axis rotational displacement in the VE.

Virtual Environments

The virtual environments consisted of three mazes of varying complexity - a simple training maze, a simple experimental maze, and a complex experimental maze The mazes were designed so that the paths through them were non orthogonal. A plan and subject's eye view of the mazes are shown in Figures 16 and 17. The mazes extended over an area of approximately 250 by 250 units. A fog effect reduced visibility in the maze to 50 units. In some conditions path markers showed the route to be learned. Collision detection was implemented such that subjects could pass through the interior walls, but not the exterior walls of the maze. Maze difficulty was varied by manipulating the total path distance and degrees of turning.

Design and procedure

The independent variables were controller type (VMC and joystick (contracted to SW for Sidewinder)), and maze difficulty. The controller type was tested between subjects, and maze difficulty was tested within subjects. Table 3 shows the order in which the experiment was conducted. The training, easy maze, and difficult maze conditions were tested with the same protocol (described below), with the exception that in the training condition subjects were encouraged to ask questions and any problems were sorted out. Each maze condition consisted of a learning phase of 5 trials with the path markers, during which the subject tried to learn the route. After each trial the subject was transported back to the start of the maze and asked to point to the exit and report their pointing confidence, and their confidence of route replication without markers. After 5 learning trials the path markers were removed and the subject then had 2 trials in which they tried to replicate the route. After 2 replication trials the subject did 2 trials in which they tried take the shortest straight line route to the exit, passing through any interior walls to do so. Before the training session subjects read instructions and completed a Sickness Symptom Questionnaire (SSQ) (Kennedy et al 1993). Subjects were given a short break between the training, easy, and difficult mazes, and after the difficult maze they were given another SSQ and a session feedback form.

We decided against counter balancing maze difficulty because of the possibility of asymmetric transfer (e.g. a different strategy being used and transferred when the easy maze was presented first than when the difficult maze was presented first).

Dependent variables

The dependent variables reported here are: MARKERS HIT (subjects were instructed to pass over or "hit" all of the route markers in the learning phase), DISTANCE PER MARKER (distance traveled as the subject went from route marker to route marker during the learning phase - a measure of the precision of maneuvering), PERCENT LOST (the percent of participants who got lost during the straight line phase, as determined by their paths making two or more loops, and/or by them making two or more incorrect course corrections), DISTANCE (distance traveled from the entrance to the exit during the straight line phase, for the trials in which the subjects were not lost), ESTIMATED ANGLE (subjects used a head-fixed reticle to point to the exit from the entrance at the end of each learning trial). The location of the subject was sampled and recorded every second. A number of other dependent variables were derived from this information, but are not reported here.

Subjects

Thirty people (12 females and 18 males) participated in the experiment. Most were staff and students at the University of Washington. Their ages ranged from 18 to 50.

Results

The results can be considered to consist of maneuvering performance, route replication performance or route knowledge, and survey knowledge. Route knowledge, as measured by the confidence with which subjects felt they could replicate the route, and their performance at doing so, was not significantly different across the devices. These data will not be presented here.

Maneuvering performance was slightly worse with the VMC. The number of markers hit, shown in Figure 18, indicates that with the VMC the participants hit slightly less markers than with the joystick (Mann-Whitney U-Test $U=73.5$, $p=0.10$). This trend is consistent with the distance per marker, shown in Figure 19, which indicates a small, but significant benefit of using the joystick ($U = 1.0$, $p<0.05$). The explanation is that (1)the VMC required more motion for control actions than the joystick (2) unlike the joystick, the VMC turned corners in a series of straight lines, resulting in less precise path control (3) the VMC was a research device, and was not as optimized for control as the commercial joystick and (4) most subjects had more experience with joysticks than with the VMC.

Survey knowledge, as measured by how well subjects could find, or point to, a straight line path to the exit, was much better with the VMC. Figure 20 shows the percentage of people who became lost when asked to go straight to the exit. Participants using the joystick were more than 3 times as likely to get lost as participants using the VMC (18.3% vs 5.1%). The difference between devices was not significant with the simple maze ($Z=1.23$, $p = 0.10$), but was significant for the complex maze ($Z=1.98$, $p <0.05$). The shortest straight line paths for the simple and complex mazes were 207 and 209 units respectively. Figure 21 shows that the mean distance for the simple maze was just under 300 units, and that the joystick and VMC performed about equally well. However with the complex maze the VMC significantly outperformed the joystick. A mixed factor ANOVA shows that the interaction was significant ($1,28$ $F=4.84$ $p<0.05$). Finally, the pointing angle data in Figure 22 indicate how well the subjects were able to assess the direction of the exit from the entrance during all the trials in the route learning phase. The VMC group had significantly smaller pointing errors ($1,28$ $F= 13.20$ $p<0.01$). Pointing was more

accurate in the simple maze (1, 28 $F=22.54$ $p<0.01$). The maze x device interaction was also significant (1,28 $F=4.85$ $p<0.05$).

Discussion

The results provide evidence that the VMC enhances certain aspects of navigation performance in virtual environments. Specifically, users were able to create a more accurate mental map of the space with the VMC than with a joystick. The enhancement was dependent on the complexity of the maze, with more complex mazes showing more of a benefit for the VMC. The results point to an interesting line of research to determine why.

References

Bliss, James P., Tidwell, Philip D., & Guest, Michael A. (1997). The effectiveness of virtual reality for administering spatial navigation training to firefighters. *Presence*, 6, 73-86.

Durlach, Nathaniel I., & Mavor, Anne S. (Eds.). (1995). *Virtual reality: scientific and technological challenges*. Washington, D. C.: National Academy Press.

Kennedy, Robert S., Lane, Norman E., Berbaum, Kevin S., & Lilienthal, Micahael G. (1993). Simulator sickness questionnaire: An enhanced method for quantifying simulator sickness. *International Journal of Aviation Psychology*, 3(3), 203-220.

Regian, J. W., Shebilske, W. L., & Monk, John M. (1992). Virtual reality: A instructional medium for visual-spatial tasks. *Journal of Communications*, 42(4), 136-149.

Ruddle, Roy A., Randall, Sally J., Payne, Stephen, J., & Jones, Dylan, M. (1996). Navigation and spatial knowledge acquisition in large-scale virtual buildings: An experimental comparison of immersive and desk-top displays. In Massimo Bergamasco (Ed.), *Proceedings of the 2nd FIVE International Conference*, (19-20 December 1996), 125-134.

Satalich, Glenna A. (1995). Navigation and wayfinding in VR: Finding the proper tools and cues to enhance navigational awareness. Unpublished masters thesis, University of Washington, Seattle, Washington.

Thorndyke, Perry W., & Hayes-Roth, Barbara (1982). Differences in spatial knowledge acquired from maps and navigation. *Cognitive Psychology*, 14, 560-589.

Tlauka, Michael, & Wilson, Paul N. (1994). The effect of landmarks on route-learning in a computer-simulated environment. *Journal of Experimental Psychology*, 14, 305-313.

Welch, Robert B., & Warren, David H. (1986). Intersensory interactions. In K. Boff, L. Kaufman, & J. Thomas (Eds.), *Handbook of perception and performance*: Vol 1. Sensory Processes and Perception, (pp. 25-1 - 25-36). New York: Wiley.

Wells, M., Peterson, B., & Aten, J. (1996). The virtual motion controller: A sufficient-motion walking simulator. (HITL Technical Report R-96-4). Seattle, WA: Human Interface Technology Laboratory. http://www.hitl.washington.edu/projects/vmc/papers.html

Witmer, Bob. G., Bailey, John H., Knerr, Bruce W., & Parsons, Kimberley, C. (1996). Virtual spaces and real world places: Transfer of route knowledge. *International Journal of Human-Computer Studies*, 45(4), 413-428.

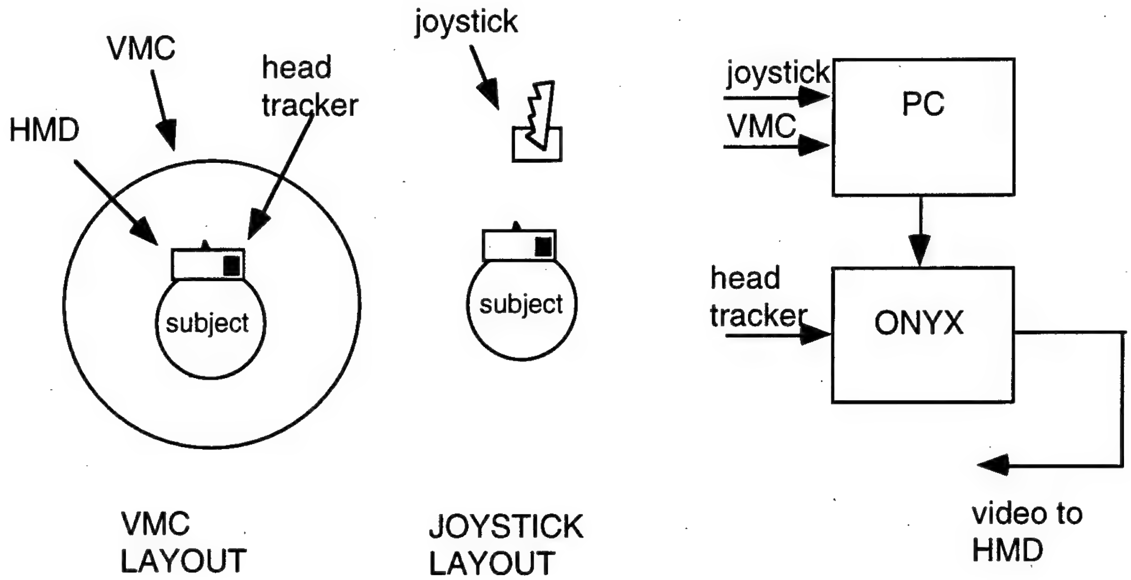


Figure 14 Diagram of the apparatus used in the experiment.

Subject	VMC				SW		
1	train	easy	diff	2	train	easy	diff
2	train	easy	diff	4	train	easy	diff
.	train	easy	diff	.	train	easy	diff
.	train	easy	diff	.	train	easy	diff
29	train	easy	diff	30	train	easy	diff

Table 3 Design of the experiment. The type of controller (VMC - virtual motion controller,. SW - Sidewinder joystick) was tested between subjects. Maze difficulty (easy, difficult) was tested within subjects.

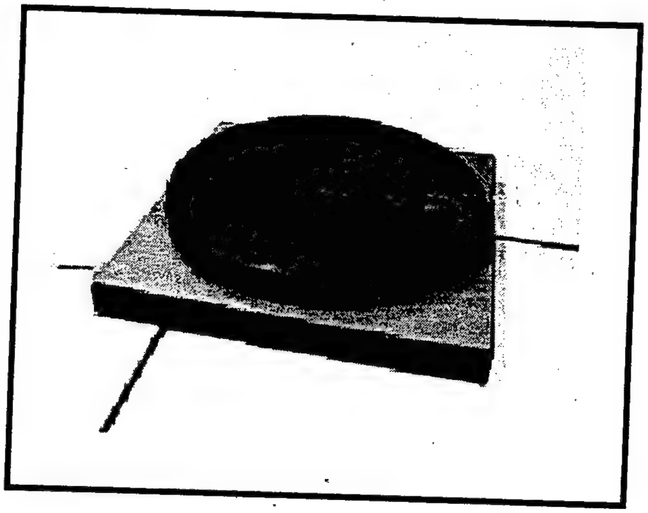


Figure 15 Photograph of the VMC and of a subject kneeling on the device.

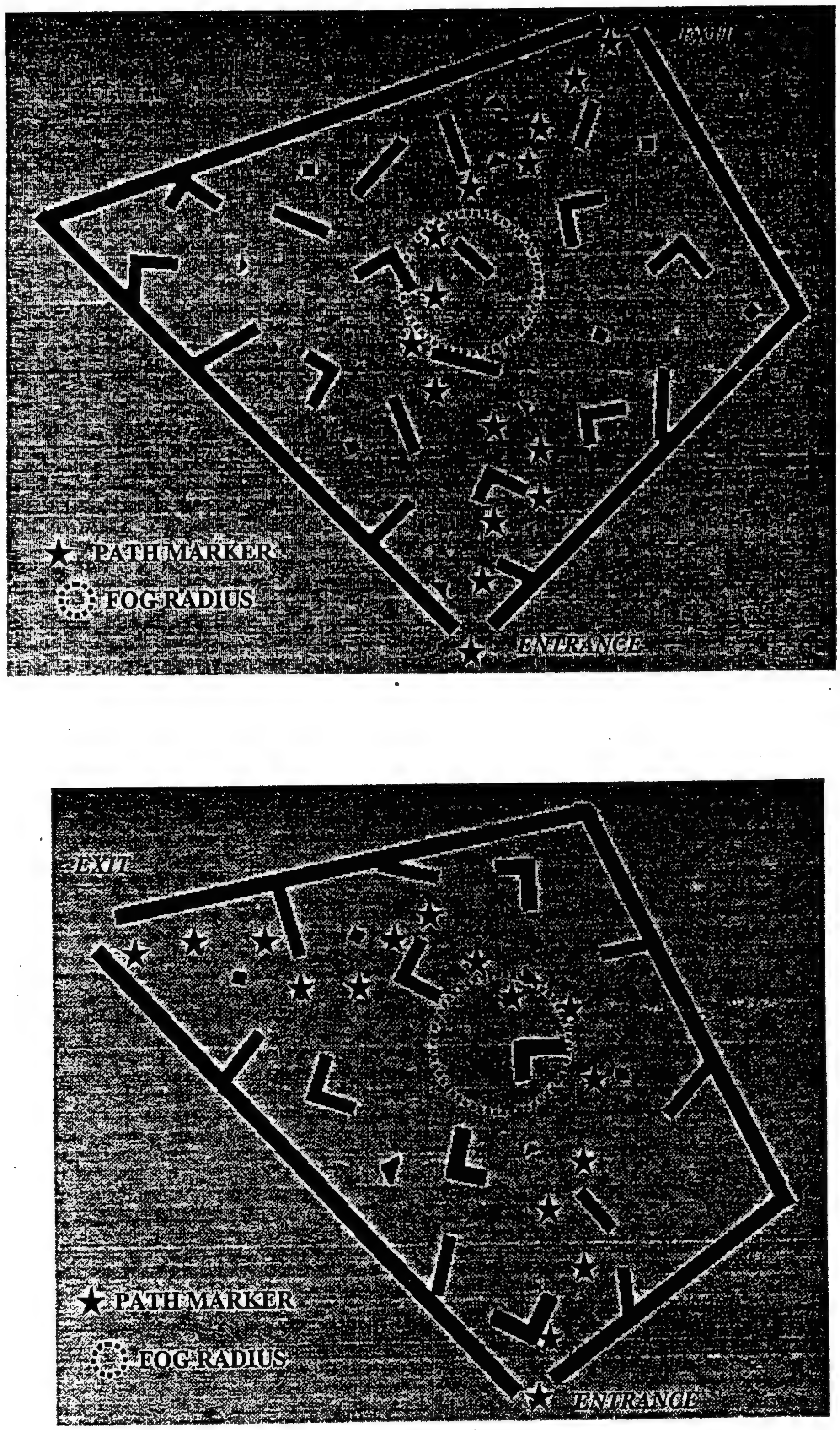


Figure 16. Plans of the simple (top) and complex (bottom) mazes.

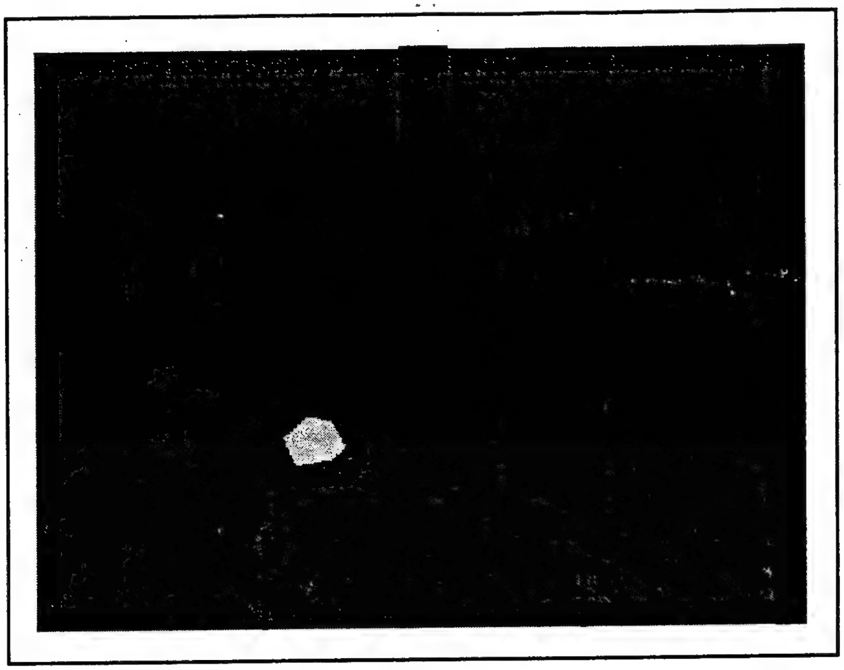


Figure 17. Immersive view of one of the mazes

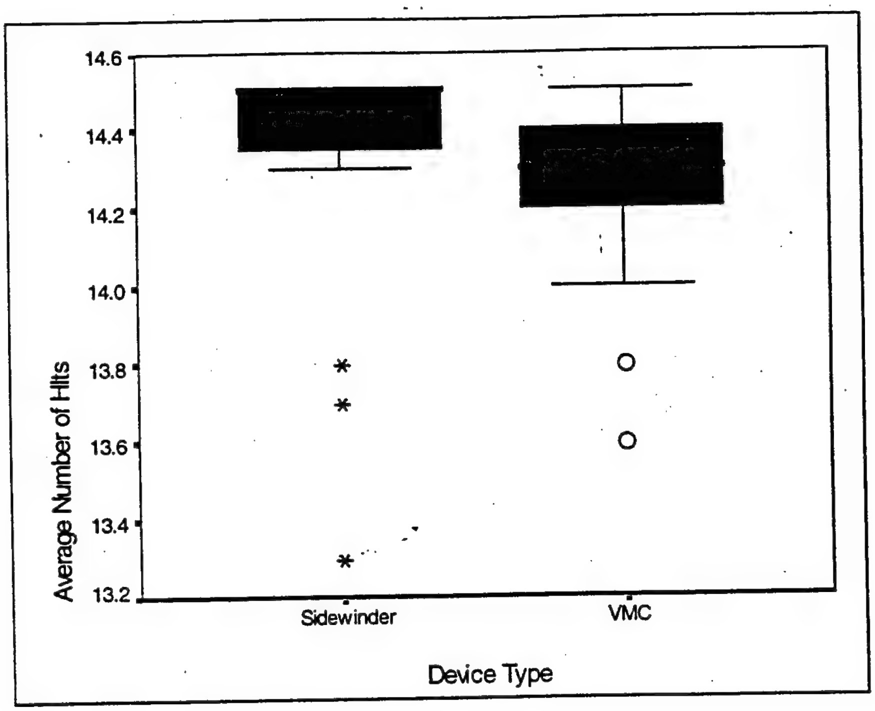


Figure 18. Average number of markers hit (more = better). There were 14 and 15 markers in the simple and complex mazes respectively.

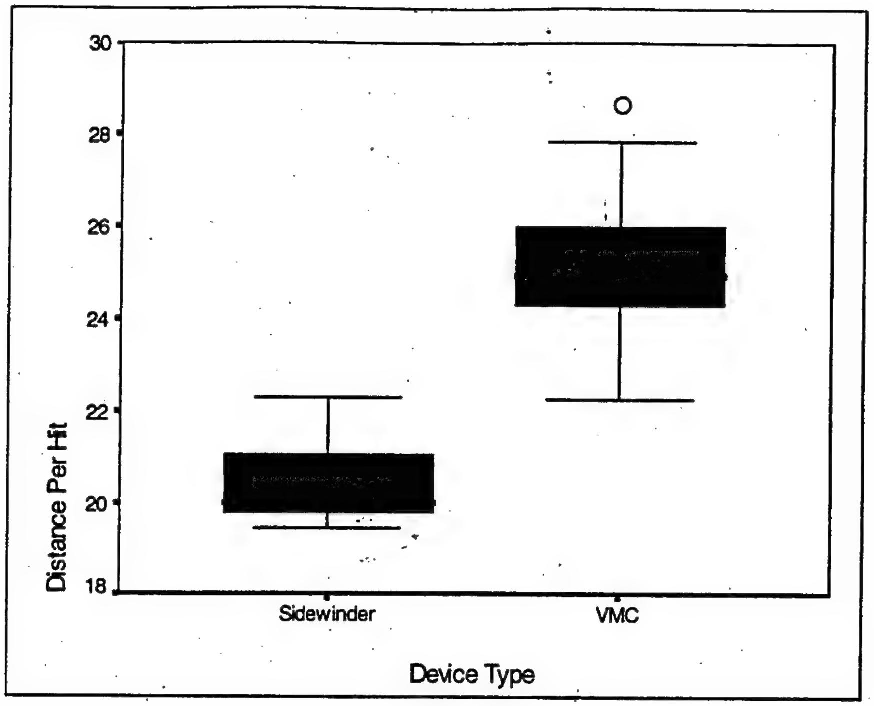


Figure 19. The distances traveled between each route marker (more = worse).

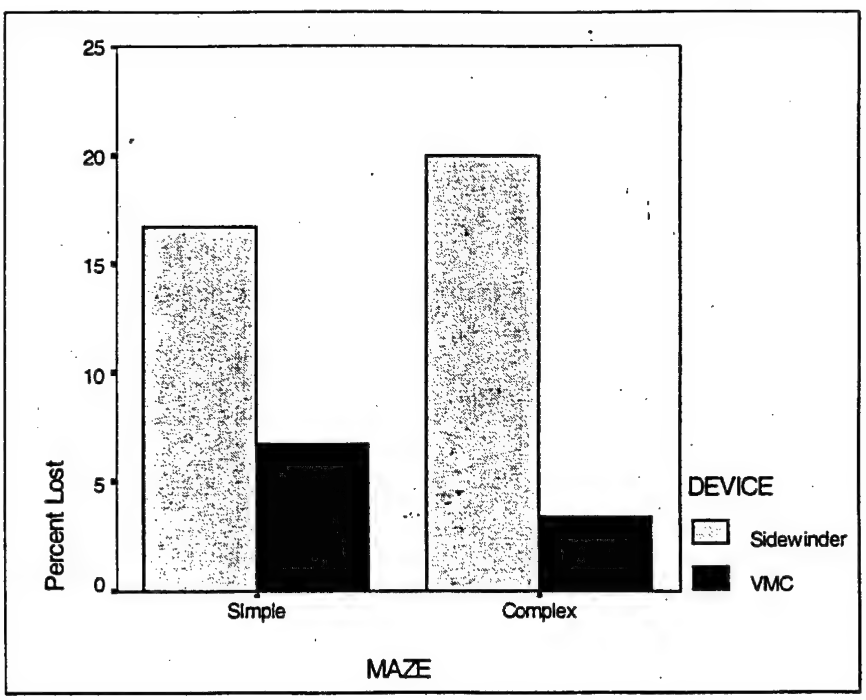


Figure 20. Percentage of subjects who got lost while trying to find a straight line route from the entrance to the exit.

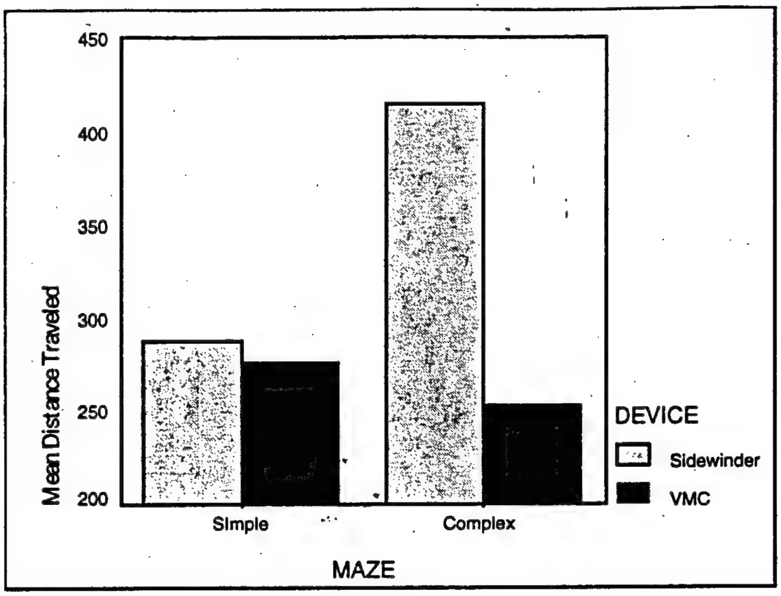


Figure 21. The distances traveled while finding a straight line route from the entrance to the exit (optimal distances were 207 and 209 units for the simple and complex mazes). The data are from the subjects who were NOT lost.

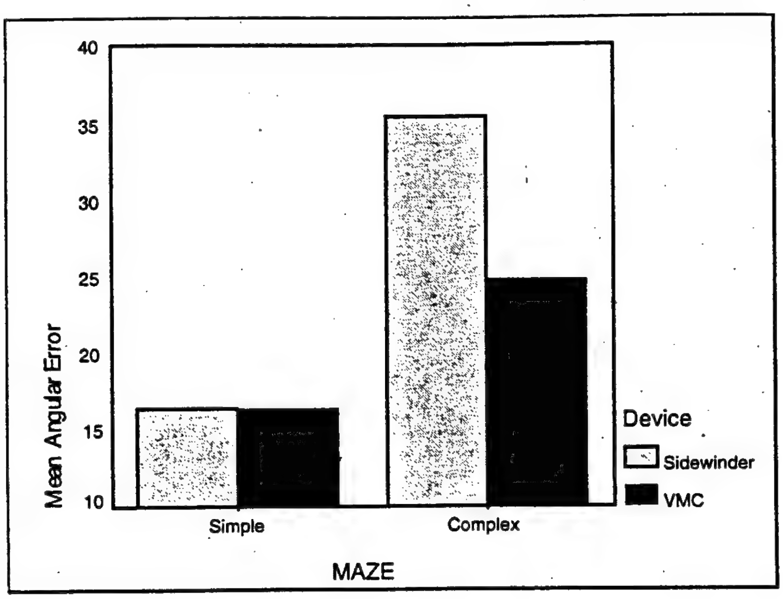


Figure 22. The estimated angular error when subject's were asked to point to the exit from the entrance.

2.4. The Go-Go Interaction Technique

As most users of virtual reality systems have discovered, grasping virtual objects that are out of reach can be challenging, especially given the often inadequate distance cues currently available. Users often find themselves flying backwards and forwards in a vain attempt to position an object within reach. This can lead to user confusion and frustration. In fact, a report by the National Research Council's Committee on Virtual Reality Research and Development [1] identified the problem of selecting and manipulating objects located outside of the user's reach as one of the most challenging problems in immersive interface development.

The Go-Go interaction technique allows immersed participants to select and manipulate any virtual object in sight without having to reposition their virtual body. The direct manipulation technique is based on the metaphor of being able to change arm length at will (Figure 1), and was named the "Go-Go interaction technique," after the cartoon character Go-Go Gadget, who had the unique ability to telescope his arms beyond normal reach.

The Go-Go metaphor is implemented by using a nonlinear function for mapping the movement of the user's physical hand to the affected movement of the virtual hand (Figure 2). To reach and manipulate distant objects, the user extends a hand toward the object of interest and, because the mapping uses a nonlinear positioning function, the user's area of reach is expanded beyond normal. To allow for nearby manipulation, a step function is used: the mapping is linear in the space close to the user and accelerates smoothly as the user extends her physical arm outside of the envelope of linear manipulation.

Preliminary user evaluations indicate the Go-Go interaction technique is extremely intuitive, as it imitates real world human behavior: when we want to reach a remote object we stretch an arm toward it. It is thus the only technique which allows seamless direct manipulation of objects both near and far.

[1] Durlach N. and Mavor A., Eds. "Virtual Reality: Scientific and Technological Challenges," National Academy Press, 1995, p. 542.

Related publications:

Poupyrev, I., Billinghurst, M., Weghorst, S., Ichikawa, T. "Go-Go Interaction Technique: Non-Linear Mapping for Direct Manipulation in VR. In Proceedings of UIST '96, pp. 79-80 (Postscript, HTML)

Poupyrev, I., Billinghurst, M., Weghorst, S., Ichikawa, T. "The Go-Go Interaction Technique for Direct Manipulation in VR" Technical Sketch at SIGGRAPH '96, 1996 (Postscript)

3. Cumulative Publications

1993

Barfield, W., & Weghorst, S. (1993). The Sense of Presence within Virtual Environments: A Conceptual Framework. In G. Salvendy & M. J. Smith (Eds.), *Human - Computer Interaction: Software and Hardware Interfaces*, (pp. 699-704). New York, NY: Elsevier.

King, W. J.(1993). Investigation of the Exhibition of Facial Expressions within Human Computer Interaction. *Proceedings of the 2nd IEEE International Workshop on Robot and Human Communication '93*, 182-187.

1994

Hendrix, C.M. (1994). *Exploratory Studies on the Sense of Presence in Virtual Environments as a Function of Visual and Auditory Display Parameters.* Unpublished Masters Thesis, University of Washington, Seattle, WA. [On-line]. Available WWW: http://www.hitl.washington.edu/projects/afosr/hendrix/

Hendrix, C., & Barfield, W. (1994). Compression and Geometric Field of View as Factors in the Design of Perspective Displays. *5th European Symposium on Space Environmental Control Systems.*

Hoffman, H.G, Hullfish, K.C, & Houston, S. (1994). Virtual Reality Monitoring. *Proceedings of the 35th Annual Meeting of the Psychonomics Society '94*

Hollander, A. (1994). *An Exploration of Virtual Auditory Shape Perception.* Unpublished Master's Thesis, University of Washington, Human Interface Technology Laboratory, Seattle, WA, USA. [On-line]. Available WWW: http://www.hitl.washington.edu/publications/hollander/

Hollander, A (1994). Perception of Virtual Auditory Shapes (HITL Technical Report #P-94-3): ICAD '95. Addison-Wesley. [Available Online: WWW] http://www.hitl.washington.edu/publications/p-94-3/hollander.html

King, W. J.(1994). Defining Phenomena for an Emotion State Model in the Human Interface. *Proceedings of the 3rd IEEE International Workshop on Robot and Human Communication '93*, 191-195. [On-line]. Available WWW: http://www.hitl.washington.edu/projects/advanced/dyad/roman.html

Prothero, J. (1994). *A Survey of Interface Goodness Measures* (Technical Report No. R-94-1). Seattle, WA: University of Washington, Human Interface Technology Laboratory. [On-line]. Available WWW: http://www.hitl.washington.edu/publications/tech-reports/tr-94-1.pdf

1995

Barfield, W., & Hendrix, C. (1995). "Presence as function of update rate within virtual environments." Paper # 1995569. *SAE Conference 95.*

Barfield, W., & Danas, E. (1995). Comments on the Use of Olfactory Displays for Virtual Environments. *Presence: Teleoperators and Virtual Environments, 5*(1), 109-121.

Barfield, W., & Furness, T. (Eds.) (1995). *Virtual Environments and Advanced Interface Design*. New York, NY: Oxford University Press

Barfield, W., & Hendrix, C. (1995). Factors Affecting Presence and Performance in Virtual Environments. In R. M. Satava, K. Morgan, H. B. Sieburg, & et. al. (Eds.), *Interactive Technology and the New Paradigm for Healthcare*, 21-28.

Barfield, W. & Hendrix, C. (1995). The Effect of Update Rate on the Sense of Presence within Virtual Environments. *Virtual Reality: Research, Development, and Application, 1*(1), 3-15.

Barfield, W., Hendrix, C., & Bjorneseth, O. (1995). Spatial Performance with Perspective Displays as a Function of Computer Graphics Eyepoint Elevation and Geometric Field of View. *Applied Ergonomics, 26*(5), 307-315.

Barfield, W., Hendrix, C., Bjorneseth, O., Kaczmarek, K. A., & Lotens, W. (1995). Comparison of Human Sensory Capabilities with Technical Specifications of Virtual Environment Equipment. *Presence: Teleoperators and Virtual Environments, 4*(4), 329-356.

Barfield, W., & Rosenberg, C. (1995). Judgments of Azimuth and Elevation as a Function of Monoscopic and Binocular Depth Cues Using a Perspective Display. *Human Factors*, 37(1), 173-184.

Barfield, W., Rosenberg, C., & Furness, T.A. (1995). Situation Awareness as a Function of Frame of Reference, Computer-Graphics Eyepoint Elevation, and Geometric Field of View. *International Journal of Aviation Psychology*, 5(3), 233-256.

Barfield, W., Rosenberg, C., & Lotens, W. A. (1995). Augmented-Reality Displays. In W. Barfield & T. A. Furness III (Eds.) *Virtual Environments and Advanced Interface Design* (pp.542-575). New York, NY: Oxford University Press.

Barfield, W., Zeltzer, D., Sheridan, T., & Slater, M. (1995). Presence and Performance Within Virtual Environments. In W. Barfield & T. A. Furness III (Eds.) *Virtual Environments and Advanced Interface Design* (pp. 473-513). New York, NY: Oxford University Press, 1995.

Billinghurst, M. & Weghorst, S. (1995). The Use of Sketch Maps to Measure Cognitive Maps of Virtual Environments. *Proceedings of the IEEE '95 Virtual Reality Annual International Symposium* , 40-47.

Crvarich, Gina. (1995). *An Exploration of Techniques to Improve Relative Distance Judgments within an Exocentric Display*. Unpublished Masters Thesis, University of Washington, Seattle, WA. [On-line]. Available WWW: http://www.hitl.washington.edu/publications/crvarich/

Draper, M. (1995) *The Role of a Virtual Body on Spatial Awareness*. Unpublished Masters Thesis, University of Washington, Seattle, WA. [On-line]. Available WWW: http://www.hitl.washington.edu/publications/draper/

Furness, T., & Barfield, W., (1995). Introduction to Virtual Environments and Advanced Interface Design. In W. Barfield & T. A. Furness III (Eds.) *Virtual Environments and Advanced Interface Design* (pp.3-13). New York, NY: Oxford University Press.

Hendrix, C., & Barfield, W. (1995). Presence in Virtual Environments as a Function of Visual and Auditory Cues. *Proceedings of the Virtual Reality Annual International Symposium, VRAIS '95* , 74-82.

Hendrix, C., & Barfield, W. (1995). Relationship Between Monocular and Binocular Depth Cues for Judgments of Spatial Information and Spatial Instrument Design. *Displays: Technologies and Applications*, 16(3), 103-113.

Hendrix, C., Barfield. W., & Brandt, J. (1995). The Sense of Presence and Performance Within Virtual Environments as a Function of Headtracking and Stereopsis. *SAE Conference 95.*

Hoffman, H.G., Hullfish, K.C., and Houston, S. (1995). Virtual-reality monitoring. *Proceedings of the Virtual Reality Association International Symposium, 95.* (pp. 48-54). IEEE Computer Society Press, Los Alamito, CA. Also presented at the 35th meeting of Psychonomics (1994).

King, W. J.& Ohya, Jun. (1995). Agents: A Study of Phenomena in Virtual Environments. *Proceedings of the 4th IEEE International Conference in Robot and Human Communication* , 199-205.

King, W. J.& Weghorst, Suzanne J. (1995). Ear Tracking: Visualizing Auditory Localization Strategies. *Proceedings of the ACM Conference on Human Factors in Computing Systems* (CHI '95), 214-215.

Prothero, J.D., & Hoffman, H.G. (1995). *Widening the Field-of-View Increases the Sense of Presence in Immersive Virtual Environments* (HITL Technical Report No. R-95-5). Seattle, WA: University of Washington, Human Interface Technology Laboratory. [On-line]. Available WWW: http://www.hitl.washington.edu/publications/r-95-5.html

Prothero, J.D., Hoffman, H.G., Parker, D.E., Furness, T.A., & Wells, M.J. (1995). Foreground/Background Manipulations Affect Presence. *Proceedings of the 39th Annual Meeting of the Human Factors Society*, 1410-1414. [On-line]. Available WWW: http://www.hitl.washington.edu/publications/p-95-3/

Prothero, J.D., Parker, D.E., Furness, T.A. & Wells, M.J. (1995). Towards a Robust, Quantitative Measure for Presence. *Proceedings of the Conference on Experimental Analysis and Measurement of Situation Awareness,* 359-366.

Satalich, G.A. (1995). Navigation and Wayfinding in Virtual Reality: Finding the Proper Tools and Cues to Enhance Navigational Awareness. Unpublished Masters Thesis, University of Washington, Seattle, WA. . [On-line]. Available WWW: http://www.hitl.washington.edu/publications/satalich/

Williamson, R. & Williamson, M. (1995) Cognitively Compatible Presentation of Uncertain Information. Unpublished poster session presented at the *Human Computer Interface International Conference.*

Winn, W.D., Hoffman, H.G, & Osberg, K.M. (1995). *Semiotics and the design of objects, actions and interactions in virtual environments.* Presented at the Invited Symposium, "Semiotics and Cognition: Issues in the symbolic design of learning environments", held at the annual meeting of the American Educational Research Association, San Francisco, April.

1996

Draper, M.H. (1996). *Can Your Eyes Make You Sick?: Investigating the Relationship Between the Vestibulo-ocular Reflex and Virtual Reality* (HITL Technical Report No. R-96-3). Seattle, WA: University of Washington, Human Interface Technology Laboratory. [On-line]. Available: WWW http://www.hitl.washington.edu/publications/r-96-3/

Draper, M. H, Wells, M. J., Gawron, V., J., & Furness, T. A. (1996). Exploring the Influence of a Virtual Body on Spatial Awareness. *Human Factors and Ergonomics Society* , 1146-1150.

Hendrix, C., & Barfield, W. (1996). The Sense of Presence within Auditory Virtual Environments. *Presence: Teleoperators and Virtual Environments, 5*(3), 290-301.

Hendrix, C., Barfield, W. (1996). Presence within Virtual Environments as a Function of Visual Display Parameters. *Presence: Teleoperators and Virtual Environments,* 5(3), 274-289.

Hoffman, H.G., Wells, M., Carlin, A., and Weghorst, S. (1996). Tactile augmentation in virtual environments. Demonstration presented at *the ACM Symposium on User Interface Software and Technology, UIST '96*, Seattle, WA.

Hoffman, H.G., Groen, J., Rousseau, S., Hollander, A., Winn, W., Wells, M., & Furness III, T. (1996). Tactile Augmentation: Enhancing Presence in Inclusive VR with Tactile Feedback from Real Objects. *Presented at the meeting of the American Psychological Society*, [On-line]. Available WWW: http://www.hitl.washington.edu/publications/p-96-1.html

Hullfish, K.C. (1996). *Virtual Reality Monitoring: How Real is Virtual Reality?* Unpublished Masters Thesis, University of Washington, Seattle, WA. [On-line]. Available WWW: http://www.hitl.washington.edu/publications/hullfish/

King, W. J., & Ohya, J. (1996).The Representation of Agents: Anthropomorphism, Agency, and Intelligence. *Proceedings of the CHI '96: ACM conference on Human Factors in Computing Systems*, 289. [On-line]. Available WWW: http://info.acm.org/sigchi/chi96/proceedings/shortpap/King/kw_txt.htm

Parker, D.E., Harm, D.L., Sandoz, G.R., & Skinner N.C. (1996). Perceived Self-Motion Assessed by Computer-Generated Animations: Sensitivity and Reliability. *Journal of Vestibular Research* , 6:S6. Also presented at Barany Society, Sydney Australia, August, 1996.

Poupyrev, I., Billinghurst, M., Weghorst, S.& Ichikawa, T. (1996). The Go-Go Interaction Technique: Non-Linear Mapping for Direct Manipulation in VR: Unpublished Technical Sketch, *ACM SIGGRAPH '96.*

Poupyrev, I., Billinghurst, M., Weghorst, S., & Ichikawa, T. (1996). The Go-Go Interaction Technique: Non-Linear Mapping for Direct Manipulation in VR. *Proceedings of the ACM Symposium on User Interface Software and Technology, UIST '96,* 79-80. [On-line]. Available WWW: http://www.hitl.washington.edu/publications/p-96-4/

Viirre, E. (1996). Virtual Reality, a New Technology for Vestibular Research. *Journal of Vestibular Research* , 6:S74. Also presented at Barany Society, Sydney Australia, August, 1996.

Wells, M.J., Baldis, S., & Hoffman, H.G. (1996). The Virtual Pilot. Presentation at the Colloquium on Multi-Crew Performance in Complex Military Systems, held at the 30th Annual Meeting of the Human Factors and Ergonomics Society in Philadelphia, September 2-6.

Wells, M.J., Peterson, B.N. & Aten, J. (1996). *The Virtual Motion Controller: A Sufficient Motion Walking Simulator* (Technical Report No. R-96-4). [Available online http://www.hitl.washington.edu/publications/r-96-4). Seattle, WA: University of Washington, Human Interface Technology Laboratory

1997

Barfield, W., Hendrix, C. & Byrstrom, K. (1997). Visualizing the Structure of Virtual Objects Using Head Tracked-Stereoscopic Displays. Manuscript in preparation for *Proceedings of the Virtual Reality Annual International Symposium,* VRAIS '97.

Carlin, A.S., Hoffman, H.G. & Weghorst, S. (1997). Virtual reality and tactile augmentation in the treatment of spider phobia: A case study. *Behaviour Research and Therapy, 35*, 153-158.

Hendrix, C., & Barfield, W. (in press). Spatial Discrimination in Three-Dimensional Displays as a Function of Eyepoint Elevation. Manuscript in preparation for *Human Factors Journal.*

Hoffman, H.G. (1997). The role of memory strength in reality monitoring decisions: Evidence from source attribution biases. *Journal of Experimental Psychology: Learning, Memory and Cognition, 23,* 371-383.

Hoffman, H.G. (1997). Therapeutic applications of VR for burn pain reduction and treatment of spider phobia. Invited presentations at Japan University in Tokyo, to a group of computer science college students in Toluca Mexico, to the Amercian Psychiatric Association in D.C., and to the University of Kansas Medical Center.

Hoffman, H.G. (1997). Virtual Reality, a new tool for interdisciplinary Psychology research.. 50 min paper presented at the annual meeting of the American Psychological Society, Washington, D.C.

Hoffman, H.G., Carlin, A.S., & Weghorst, S. (1997). Virtual reality and "mixed reality" in the treatment of spider phobia: A case report. Paper presented at the Medicine meets VR conference, Jan. 22-25, 1997, San Diego, Calif.

Hoffman, H.G., Doctor, J.N., Patterson, D.R., Carrougher, G.C., Taylor, W., Weghorst, S., and Furness, T. III. (1998). VR for burn pain control during wound care.. Paper presented at Medicine Meets VR 6, San Diego CA.

Osberg, K., Rose, H., Winn, W., Hollander, A., Hoffman, H., and Char, P. (1997). The Effect of Having Grade Seven Students Construct Virtual Environments on their Comprehension of Science. Presented at the Annual Meeting of the American Educational Research Association, March 1997.

Wells, M.J., Peterson, B.N. & Aten, J. (1997). The Virtual Motion Controller: A Sufficient Motion Walking Simulator. Submitted to *Proceedings of the Virtual Reality Annual International Symposium ,VRAIS 1997.*

Wells, M.J. & Hoffman, H.G. (1997). Task allocation between real and virtual pilots: Putting real intelligence into a virtual cockpit. Paper presented at the 2nd Annual Symposium and Exhibition on Situational Awareness in the Tactical Air Environment. Naval Air Warefare Center, Patuxent River, Maryland.

Winn, W., Hoffman, H., Hollander, A, Osberg, K, and Rose, H. (1997). The Effect of Student Construction of Virtual Environments on the Performance of High- and Low-Ability Students. Presented at the Annual Meeting of the American Educational Research Association, Chicago, March 1997

1998

Draper, M.H. (1998). The adaptive effects of virtual interfaces: vestibulo-ocular reflex and simulator sickness, Unpublished doctoral dissertation, University of Washington, Seattle.

Hoffman, H.G., Prothero, J., Wells, M. & Groen, J. (in press). Virtual Chess: The role of meaning in the sensation of presence. *International Journal of Human-Computer Interaction.*

Hoffman, H.G. (1998). Physically touching virtual objects using tactile augmentation enhances the realism of virtual environments.. *Proceedings of the Virtual Reality Annual International Symposium* '98, (pp. 59-63), Atlanta GA.

Hoffman, H.G. (1998). Medical and Clinical Applications of Immersive Virtual Reality. Paper to be presented at SIGGRAPH '98. Orlando Florida, and at the Americal Psychiatric Association, Los Angeles, CA., Oct., 98.

Hoffman, H.G. (in press). Virtual Reality: A new tool for interdisciplinary Psychology research. *CyberPsychology & Behavior: The impact of the internet, Multimedia and virtual reality on behavior and society.*

Hoffman, H.G, Granhag, A. & Loftus, E.F. (in preparation). The role of conformity in the creation of false memories.

Hoffman, H.G., Doctor, J.N, Patterson, D.R., Carrougher, G., Taylor, W., Weghorst, S., & Furness, T. (under revision). Use of virtual reality for adjunctive treatment of pediatric and adolescent burn pain: A case report. Submitted to a medical journal.

Loftus, E.F., Nucci, M., & Hoffman, H.G. (in press). Manufacturing Memory. *American Journal of Forensic Psychology.*

Peterson, B.N. (1998) The influence of whole-body interaction on wayfinding in virtual reality. , Unpublished Masters thesis, University of Washington, Seattle.

Peterson, B.N., Wells, M.J., Furness, T.A. and Hunt, E. (in preparation) An interface to enhance navigation in virtual environments. To be presented at the Annual Conference of the Human Factors and Ergonomics Society.

Prothero, J.D. (1998). The Role of Rest Frames in Vection, Presence & Motion Sickness. Doctoral Dissertation, University of Washington.

Winn, W., Hoffman, H., and Osberg, K. (in press). Semiotics and the Design of Objects, Actions and Interactions in Virtual Environments. *Journal of Structural Learning.*

Winn, W.. Hoffman, H., Hollander, A., Osberg, K., and Rose, H. (in press). The Effect of Student Construction of Virtual Environments on the Performance of High- and Low-Ability Students. *Presence: Teleoperators and Virtual Environments.*

4. Professional Personnel

Thomas A Furness III (Director, HIT Lab)
B.A. Electrical Engineering, 1966, Duke University.
Ph.D. Engineering and Applied Science, 1981, University of Southampton, England.

Hunter Hoffman (Research Staff, HITL)
B.S. Psychology, 1985, The University of Tulsa, OK.
M.S. and Ph.D. 1992, Cognition and Perception, minoring in Physiological Psychology, University of Washington, Seattle, "Reality monitoring: the process by which people separate memories of real events (fact) from imagined events (fantasy)."

Donald E. Parker (Adjunct Professor, Dept. of Otolaryngology, UW)
B.A. Psychology/Economics (1958), DePauw University, IN
Ph.D. Experimental Psychology (1961), Princeton University, NJ, "Vertical organization of the auditory cortex in the cat."

Erik Viirre (Research Scientist, Human Interface Technology Laboratory)
Ph.D. (Physiology), 1987, University of Western Ontario, London, Canada, "Independent Control of the Eyes During Saccades and the VOR".
M.D., 1988, University of Western Ontario, London, Canada
Graduate, 1988, International Space University, Summer Session, Cambridge, Mass.
Intern, 1989, St Joseph's Health Centre, London, Canada
Fellow, 1990-93, Robarts Research Institute, Imaging Research Group, London, Canada
Visiting Assistant Professor, 1994-5, National Vestibular Disorders Center, Department of Neurology, UCLA, Los Angeles, California.
Visiting Assistant Professor, 1994-5, Jules Stein Eye Institute, Department of Ophthalmology, UCLA, Los Angeles, California.

Suzanne J. Weghorst (Director of Human Factors and Interface Development, HIT Lab)
B.S. Psychology, 1972, Seattle University.
M.A. Psychology, 1975, University of California, Riverside.
Ph.D. (candidate), Psychology, 1977, University of California, Riverside, "A Sociobiological Approach to Human Jealousy."
M.S., Computer Science, 1989, University of Washington, "Exploring Graph Perception with an Automated User Interface Research Tool"

Maxwell J. Wells (Associate Director, HIT Lab)
B.Sc. (Honors) Biology and Psychology, 1978, University of Stirling, Scotland.
Ph.D. Engineering and Applied Science, 1983, University of Southampton, England, "Vibration-induced eye movements and reading performance with the helmet-mounted display."
CPE (Certified Professional Ergonomist) 1993.

5. Ongoing and Future Research

One of the goals of the AFOSR MURI program was to initiate research at HITL. This was successfully accomplished. Some of the research thrusts have taken on a life of their own, with some evolutionary changes. Some current and proposed research efforts with direct links to this grant are described below.

5.1. Computer-mediated communication

5.1.1. The SHARE Consortium

In December 1996 Boeing created a consortium of participants who can contribute to the building of the SHARE vision. These include Microvision - the makers of the Virtual Retinal Display, GEC - a helmet-mounted avionics manufacturer, Boeing - as the prime integrator, and the HIT Lab - for concept development and as the research and development arm. The original consortium submitted a proposal to DARPA under the Warfighter Visualization program. This proposal was not funded, but the consortium lived on and continued to incubate the concept and generate components with their own resources. In December of 1997 a briefing was given to the Army and Navy at a meeting at Boeing. Prospective additions to the consortium include Gentex - helmet and helmet-mounted display integrators, and Applied Sciences Laboratory - eye tracker manufacturers.

The consortium represents an amalgamation of industrial and academic entities with a clear vision, momentum, and a commitment to the successful integration of technology to enhance military performance.

Future experiments

We are designing a series of experiments which will provide a better understanding of the issues being raised by the current work, and which will address questions relevant to the future implementation of the ViP concept. These include:

- The effects of transactive memory (using the same vs. different advisors)
- Advisor and pilot skill level
- The contributions of the various channels of communication
- The most appropriate technological implementation (e.g. VR vs. video)
- The effects of workload
- The role of eye movement (and other technology enhanced communication options)

5.1.2. Knowledge and Distributed Intelligence

We have responded to an NSF call for proposals, using the ViP work as a base. Below is our letter of intent.

Project Title: Knowledge Profiler
KDI Focus: Knowledge Networking

Project Description:

In the paradigm of knowledge networking mediated by computers, there remain three key interactions which can impact the way in which knowledge is created, communicated and valued. These are: (1) human-to-computer interactions, (2) computer-to-human interactions and (3) human-to-human interactions. We believe that improvements in any one can create substantial payoffs, but that 1 and 2 are high risk (we are a long way from

understanding the fundamental components of real or artificial intelligence that would be required for peer-to-peer communication). The risk can be reduced, while maintaining most of the benefit, by creating a hybrid system in which a human interprets the output from a computer and communicates that to another human. In essence this is a fourth option, termed computer-to-human-to-human interaction. The benefits of this sort of interaction occur, for example, between an advisor and a person being advised, where the person receiving advice cannot devote the attentional resources required to deal with an unintelligent machine. Apart from improving performance, this fourth option also provides a rich testbed for understanding the nature of the communication of knowledge. This understanding could, in due course, be used increase machine intelligence.

One factor that we have identified as being important in this type of knowledge transfer is that the advisor be aware of the state of knowledge of the person being advised. We propose the creation of a Knowledge Profiler, which uses a combination of display design, eye movement tracking, and other behaviors to provide information to the advisor about what advice is needed.

The project will match a technology push, as represented by the lines of research being pursued by some members of the team, with a requirements pull, as represented by the need for collaborative innovation and knowledge sharing brought by the industrial partners. The research to be leveraged includes (1) the SHARE project, in which members of a team use shared augmented reality to vanquish the limitations of time and distance (2) TADMUS, which uses decision theory and human-system interaction technology in a decision support system and (3) the Virtual Pilot project, which uses eye tracking as a way to communicate situation awareness between a pilot and an advisor.

5.2. Motion sickness and the Rest Frame Hypothesis

5.2.1. VMC

We have continued to work on the VMC. Our most recent experiment seeks to explain why the VMC is better at creating survey knowledge. Our first exploration manipulated whether or not subjects received "functional distal cues". In other words, we manipulate whether subjects could see around the edges of the head-mounted display to view the laboratory. Our hypothesis is that the subjects use the stationary landmarks in the lab as landmarks in the virtual world. We used blinders which blocked the subjects view of anything other than the content of interest on the head-mounted display. Coincidentally, this also determines whether or not subjects have a stationary visual background. The rest frame hypothesis would predict that there should be more sickness in the blinders-on condition. To our dismay, this proved to be the case, and we had to change our method of blocking the subjects' view of the laboratory.

5.2.2. Driving simulator

We have written a proposal, in partnership with a company called Motion Research, to create a driving simulator that does not suffer from the problems of simulator induced sickness. The abstract is shown below:

The Auto racing simulator industry to date has been primarily the preserve of the entertainment industry. While the entertainment industry continues to develop and produce increasingly sophisticated games, there is a limit to the fidelity that they will need or accomplish. Motion Research has identified a need for a high-fidelity auto racing simulator that is more than a game and that can actually be used to train drivers preparing for a career in the auto racing industry. World wide, auto racing is a $6 billion enterprise, and it is expected to grow by more than 10% per year.

There have been several attempts to build high fidelity auto and auto racing simulators, most of which have encountered the issue of simulator sickness. This is a problem that we intend to solve. MR has access to the unit built and owned by the Chrysler Corporation to test and develop road noise and harshness damping solutions. There has been considerable work done in the field of simulator sickness with this unit, and that information is accessible to us. In addition we intend to use the skills and experience of the UW HIT lab staff, and gain access to their driving simulator.

We propose a cooperative and simultaneous approach to building a sickness-free simulator. MR will begin the definition and prototype phase of the actual simulator, while the HIT Lab conducts experiments centered around the "rest frame hypothesis" and aimed at reducing the problem of simulator sickness.

The product we intend to produce will meet several needs:

- Reduce the cost of testing for drivers moving into new forms of racing
- Minimize the risk to man and machine during these transitional periods
- Allow further development and refinement of vehicle dynamic tests without risk
- Provide a very realistic high-end racing experience for race sponsor executives and guests
- Develop a unit that can be used for initial driver training

Motion Research is uniquely qualified to develop the market and product. Its principal has over 22 years of professional racing experience and contact deep within the auto racing industry. Other principals in the company have had experience in human interface products and technology and have participated in many hours of the type of track testing that can be eliminated by a racing simulator.

Motion Research plans to employ as many as 40-50 people in the next 2-3 years as a Washington State company. These people will be responsible for the development and operation of our simulators as they are used by racing drivers at various locations.

5.3. Virtual Motion Controller and spatial awareness

5.3.1. Spatial Awareness Group

We have created a working group to conduct a literature review to answer the question "What is human spatial awareness". We are planning to submit a proposal to the ONR and to NIH to fund some of this research. ONR are interested in the training aspects of spatial awareness. We are hoping to solicit support from the NIH on the developmental aspects of spatial awareness - how it is gained in the young, and how it is lost in the old.

5.3.2. Head to Head

The VMC was licensed by a small start-up company for commercial exploitation. After conducting extensive market research the company decided that the best commercial opportunities were in the simulator markets, as against the domestic computer-game markets. Head to Head is currently negotiating with a Government agency to use the VMC in a dismounted infantry simulator.